June 2003

SHASTA LAKE
WATER RESOURCES INVESTIGATION

OFFICE REPORT

Break-Point Analysis

U.S. Department of the Interior, Bureau of Reclamation, Mid-Pacific Region

U.S. Bureau of Reclamation

Mid-Pacific Region

Shasta Lake Water Resources Investigation, California

Office Report

Break-Point Analysis

June 2003

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CHAPTER I
INTRODUCTION

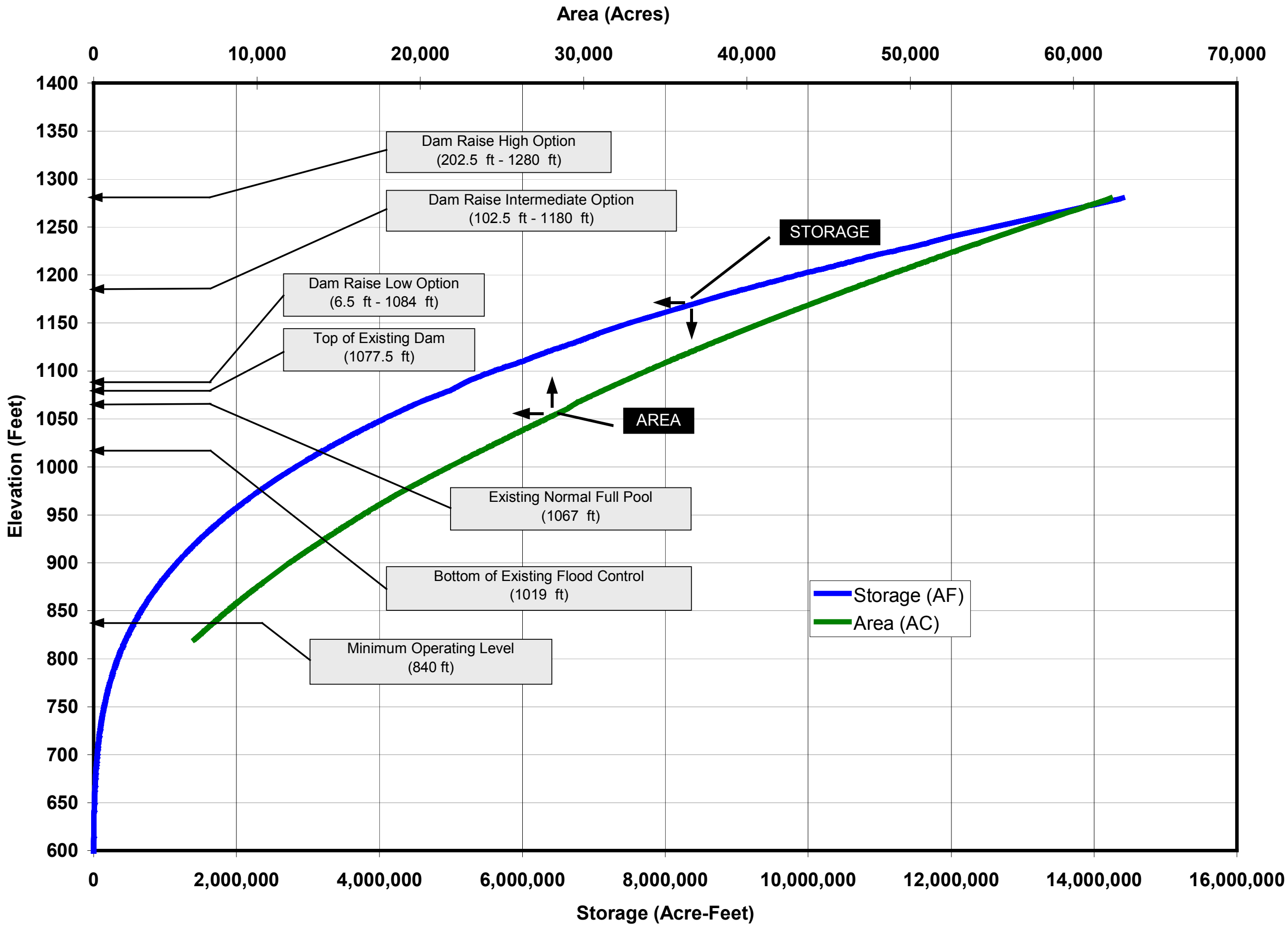
BACKGROUND

Shasta Reservoir is California's largest man-made lake with a gross pool storage capacity and surface area at the top of joint use at elevation 1067.7 (rounded to 1,070) feet msl (vertical datum NAVD 1988) of 4,552,000 acre-feet and 29,500 acres, respectively. Shasta Reservoir has approximately 370 miles of shoreline when full and has a maximum depth of 517 feet. The Shasta Dam and Reservoir project was constructed by the U. S. Bureau of Reclamation (Reclamation) as an integral element of the Central Valley Project (CVP) from 1938 to 1945 for six purposes. They include: irrigation water supply, municipal and industrial (M&I) water supply, flood control, hydropower generation, fish and wildlife conservation, and navigation. The project also supports vigorous water oriented recreation at the reservoir, which is located within the Shasta Unit of the Whiskeytown-Shasta-Trinity National Recreation Area.

Shasta Dam and Reservoir are located on the upper Sacramento River in northern California about 9 miles northwest of the City of Redding. The entire reservoir is within Shasta County. The reservoir controls runoff from about 6,421 square miles from four major tributaries including the Sacramento, McCloud, and Pit Rivers, Squaw Creek, and from numerous minor creeks and streams. Historically, essentially all outflow from Shasta Dam travels through northern California to the Sacramento-San Joaquin Delta southwest of Sacramento. The total drainage area of the Sacramento River at the Delta is about 26,300 square miles. The average annual runoff to the Delta from the Sacramento River watershed is about 17.2 million acre-feet. This represents about sixty-two percent of the total inflows to the Delta.

Shasta Dam is a curved, gravity-type, concrete structure 487 feet high above the streambed with a total height above the foundation of 602 feet. Its crest elevation is at 1,080.2 feet msl. The maximum seasonal flood control storage space in Shasta Reservoir is 1.3 million acre-feet. Shasta Dam has a crest width of 30 feet and a length of about 3,500 feet. The Shasta Power Plant consists of five main generating units with a current capacity of 625 megawatts and two station service units with a current capacity of 5 megawatts. The capacity of the five main generating units, when upgrades are completed in 2007, will be 710 megawatts. A plan view of Shasta Dam and Power Plant are shown on **Plate 1** and Shasta Dam elevations and sections are shown on **Plate 2**. **Figure 1** is the area-capacity curve for Shasta Reservoir. **Table 1** summarizes the major pertinent data and features of Shasta Dam and Reservoir.

A feasibility scope investigation was initiated in 2000 focusing on evaluating the potential to enlarge Shasta Dam primarily for increased water supply reliability and water quality improvements. Assessing the general type and scope of modifications required for various magnitudes of dam raises is an important element of the investigation. The resulting decision document will be an integrated feasibility report and Environmental Impact Statement and Report (EIS/EIR). Fundamental authorization for the Shasta Dam Enlargement Feasibility Investigation is provided under the 1980 Public Law (P.L.) 96-375. Major influencing legislation includes the Central Valley Project Improvement Act (CVPIA) of 1992 (P.L. 102-575).



Note: Elevations given on this graph are in vertical datum NGVD 1929

Figure 1 – Area-Capacity Curves for Shasta Reservoir

PURPOSE AND SCOPE

The primary purpose of this office report is to describe the results of an analysis to identify the elevations of dam raise where the project costs significantly change due to the need for relocation or modification of major project features. This information will be used to help identify the feasibility of various dam raise options. Available data from previous studies were used to the maximum extent possible.

TABLE 1
PERTINENT DATA – SHASTA DAM AND RESERVOIR

General

Drainage Areas (excluding Goose Lake Basin)	
Sacramento R. at Shasta Dam	6,421 sq-mi
Sacramento R. at Keswick	6,468 sq-mi
Sacramento R. above Bend Bridge near Red Bluff	8,900 sq-mi
Sacramento R. near Ord Ferry	12,250 sq-mi
Pit R. at Big Bend	4,710 sq-mi
McCloud R. above Shasta Lake	604 sq-mi
Sacramento R. at Delta (near head of reservoir)	425 sq-mi

Mean Annual Runoff (1908-1974)	
Sacramento R. at Shasta Dam	5,737,000 ac-ft
Sacramento R. near Red Bluff	8,421,000 ac-ft
Sacramento R. at Ord Ferry	9,812,000 ac-ft
Maximum Flows of Record (1903-1976)	
Sacramento R. at Shasta Lake 16 Jan 1974	216,000 cfs
Sacramento R. near Red Bluff 28 Feb 1940	291,000 cfs
Sacramento R. at Ord Ferry 28 Feb 1940	370,000 cfs

Shasta Dam and Reservoir

Shasta Dam *(concrete gravity)*	
Crest elevation	1080.2 ft
Freeboard above gross pool	10.5 ft
Height above foundations	602 ft
Height above streambed	487 ft
Length of crest	3500 ft
Width of crest	30 ft
Slope, upstream	Vertical
Slope, downstream	1 on 0.8
Volume	8,430,000 cu yd
Normal tailwater elevation	588 ft
Spillway (gated ogee)	
Crest length	
Gross	360 ft
Net	330 ft
Crest gates (drum type)	
Number and size	3 @ 110’ x 28’
Top elevation when lowered	1039.7 ft
Top elevation when raised	1067.7 ft
Discharge capacity at pool elevation 1067.7 ft	186,000 cfs
Flashboard gates	
Number and size	3 @ 110’ x 2’
Top elevation when lowered	1069.7 ft
Bottom elevation when raised	1072.2 ft
Outlets	
River outlets (102 in. dia. Conduit with 96 in. dia. Wheel type gate)	
4 with invert elevation	740.4 ft
8 with invert elevation	840.4 ft
6 with invert elevation	940.4 ft
Capacity at elevation 1067.7 ft	81,800 cfs
Capacity at elevation 830.4 ft	12,200 cfs
Power outlets (15’ steel penstocks)	
5 with invert elev. of intake	810.2 ft

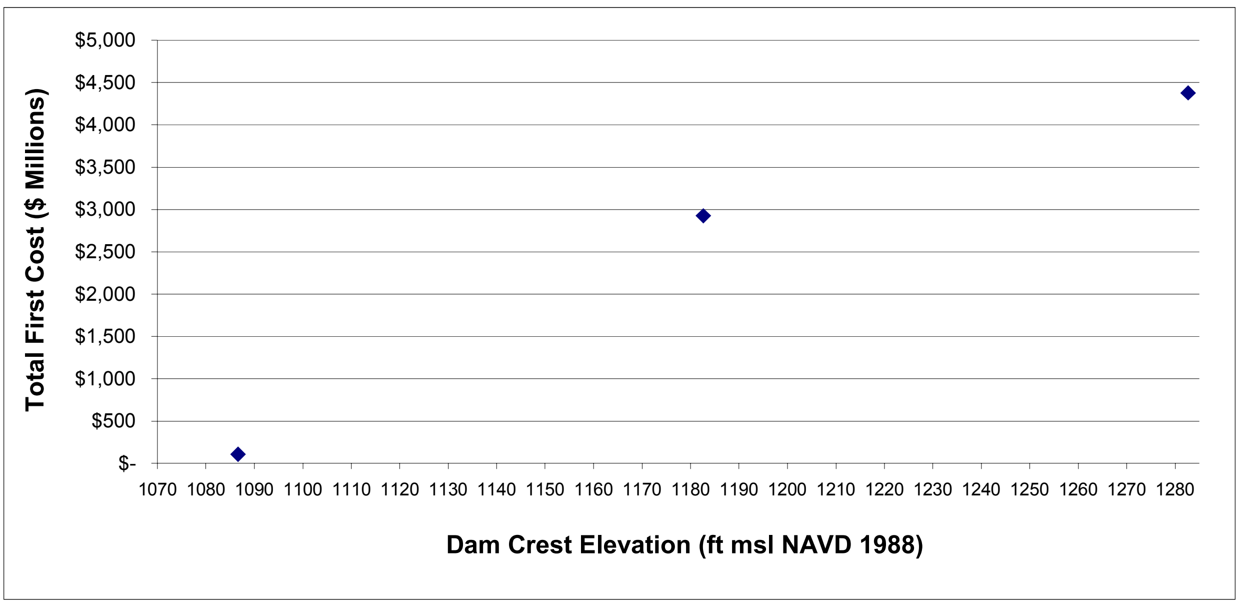
Shasta Reservoir	
Elevations	
Gross pool	1069.7 ft
Minimum operating level	842.7 ft
Taking line	Irregular
Area	
Minimum operating level	6,700 acres
Gross pool	29,500 acres
Taking line	90,000 acres
Storage capacity	
Minimum operating level	587,000 ac-ft
Gross pool	4,552,000 ac-ft
Shasta Power Plant	
Main units	
5 turbines, Francis type, total capacity	515,000 hp
5 generators, 125,000 kw each total capacity	625,000 kw
Station units	
2 generators, 2,500 kw each total capacity	5,000 kw
Elevation centerline turbines	589 ft
Maximum tailwater elevation	635.2 ft
Total discharge capacity at pool elevation 1067.7 ft	14,500 cfs
Total discharge capacity at pool elevation 830.4 ft	16,000 cfs

Note: *Elevations given are in vertical datum NAVD 1988.*

CHAPTER II
FINDINGS OF RECENT STUDIES

The potential enlargement of Shasta Dam has been studied since the 1970s. A 1999 Reclamation report titled "Appraisal Assessment of the Potential for Enlarging Shasta Dam and Reservoir" presented descriptions and cost estimates for the Low Option (6.5 feet), Intermediate Option (102.5 feet), and High Option (202.5 feet) raises of Shasta Dam. The estimated total first cost for the Low, Intermediate, and High Options were $107.5 million, $2.9 billion, and $4.4 billion, respectively. The first costs given in the 1999 Reclamation Appraisal Report included costs for materials, real estate mitigation, engineering, and construction management services. The report concluded that "The cost of the Intermediate and High Options… pose significant challenges in developing required financial packages." The results of the study led to the following recommendation: "It is recommended that feasibility studies examining a low raise option enlargement of Shasta Dam and Reservoir proceed."

The estimated first costs from the 1999 Reclamation Appraisal Report for the three options are plotted in **Figure 2**. Costs for dam raises between the Low, Intermediate, and High Options should not simply be interpolated. An accurate cost curve would have discrete "break-points" or discontinuities at elevations where the needs for major features are triggered. These primarily include major relocations or construction of significant new features. This information will be used to help evaluate the feasibility of various dam raise alternatives.



Note: Data from "Appraisal Assessment of the Potential for Enlarging Shasta Dam and Reservoir," USBR, 1999.

Figure 2 – Estimated Total First Costs for Enlarging Shasta Dam

The elevation at which the Pit River Bridge would need to be relocated is a very significant break-point because the bridge carries two major transportation routes, the Union Pacific Railroad (UPRR) and Interstate 5 (I-5). The cost of replacing the Pit River Bridge was estimated to be $340 million in the 1998 Reclamation Technical Memorandum. A plan and profile drawing of the Pit River Bridge is included on **Plate 3**. Other break-points include the elevation at which a new power plant and switchyard are required, the elevation at which cofferdams are required, the elevation at which a concrete overlay is required on the face of the dam, the elevations at which various reservoir dikes are required, and the elevation at which relocation of I-5 is required.

CHAPTER III
ANALYSIS APPROACH

GENERAL APPROACH

A 1998 Reclamation Technical Service Center Report titled "Technical Memorandum No. SHA-8130-TM-98-1: Shasta Dam and Reservoir Enlargement Initial Assessment Study, Central Valley Project, California" included cost estimate spreadsheets documenting the development of the costs for the Low, Intermediate, and High Options for raising Shasta Dam, which were presented in the 1999 Reclamation Appraisal Report. Information from the 1998 Reclamation Technical Memorandum was a primary source of data for this break-point analysis. Approximations were developed for the costs and break-points (or break-ranges) between the Low, Intermediate, and High Options. Existing information on field costs and materials for raising Shasta Dam were used to the maximum extent possible. Field costs include costs for materials and contingencies, but do not include costs for engineering and design, and construction management services.

The field costs identified in this office report are at an appropriate level of detail to identify the relative magnitude of major break-points in cost. For this report, the location of the break-points and the relative scales of the costs at certain raises in dam height and reservoir joint use levels are more important than the actual detailed costs associated with the items. Field costs (first costs less mitigation, engineering and design, and construction management) were updated to March 2003 price levels from those used in the 1998 Reclamation estimates using the ENR construction cost index. **Table 2** shows the 1998 and 2003 cost index values, as well as the 1998 to 2003 cost index escalation value.

TABLE 2
COST INDEX VALUES

Index	**Value**
February 1998 Index	5874
March 2003 Index	6627
Index Escalation	**Value**
1998 to 2003	1.13
**Index values from http://enr.construction.com/features/conEco/costIndexes/default.asp*	

This office report includes preliminary field cost estimate information on major infrastructure features associated with raising the dam and reservoir level. There are several cost factors that, although important, are not necessarily critical in helping to determine major break-points in dam raise versus cost relationships. They include:

- Environmental or mitigation costs
- Engineering, design, and construction management costs
- Land rights issues and their associated costs

- Loss of revenue from power generation caused by higher tailwater elevations on the Pit 7 power plant (or inundation of the Pit 7 power plant)

- Impacts to archaeological sites and resulting mitigation

It is believed that the costs for these factors would be proportional to the magnitude of dam raise and would not be influential to this break-point assessment. Each, however, will need to be researched further in formulation efforts to define alternative plans.

SITE VISIT AND WORKING MEETING SUMMARY

Representatives from Reclamation, California Department of Water Resources (DWR), and California Department of Transportation (Caltrans) visited major features at Shasta Dam and in the Shasta Reservoir area in May 2003 to evaluate the issues with raising the dam. The site visit fostered group discussion of break-point locations and factors, as well as recommendations for future studies. A copy of the site visit memorandum is included in the Appendix.

ANALYSIS ORGANIZATION

The items in this break-point analysis office report are organized into two main categories: (1) **Shasta Dam and Appurtenances** and (2) **Shasta Reservoir Area Infrastructure**. For each of these categories, costs are assigned for various levels of dam raise and the results are organized into cost curves. Elevations given from this point on in the report are in the North American Vertical Datum of 1988 (NAVD 1988) unless otherwise noted.

CHAPTER IV
SHASTA DAM AND APPURTENANCES

Following is a discussion of major features associated with modifications of Shasta Dam and its appurtenances for various potential dam raises up to an increase of 200 feet. Graphs of estimated field costs versus dam crest elevation are also included to illustrate the relative costs of modifying various dam components. These items primarily include:

- Concrete Dam and Wing Dams
- Dam Crest Structure Removal
- Cofferdams for Left and Right Abutments
- Spillway Modifications
- River Outlet Modifications
- Temperature Control Device Modifications
- Penstock Intake Modifications
- Penstock Modifications
- Power Plant Modifications

CONCRETE DAM AND WING DAMS

The placement of mass concrete is the most costly item, relative to the dam and its appurtenances, associated with raising Shasta Dam. This item includes the concrete required to raise the height of the dam, as well as the concrete required to build and extend the wing dams on either side of the existing embankment. The costs for spillway modifications are considered separately.

Small raises of Shasta Dam could be constructed by adding blocks of mass concrete to the existing dam crest. Large raises of Shasta Dam would require a mass concrete overlay on the downstream face of the dam. It is estimated that the mass concrete block method of raising the dam would be adequate for a raise in height about equal to its crest width. Accordingly, it appears that Shasta Dam can be raised with block construction techniques by about 30 feet. In 1993, Reclamation completed a modification of Buffalo Bill Dam near Cody, Wyoming, where the 10-foot wide dam crest was raised almost 25 feet. Buffalo Bill Dam is a high concrete arch dam completed in 1910. Future studies to assess raising Shasta Dam will need to consider the magnification of earthquake accelerations at the crest, as well as the concentration of stresses at the re-entrant corner of the existing chimney section on the downstream face. For dam raises greater than about 30 to 50 feet, overlaying the existing dam with concrete mass and progressively enlarging the dam should be considered. A dam raise of 30 feet (to elevation 1,110 feet msl) was identified as the main break-point in the cost of enlarging the concrete dam since a concrete overlay requires a significantly greater volume of concrete than the addition of concrete blocks to the crest.

The estimated volume of concrete required for dam raises up to 30 feet used the current length of the concrete section of the dam and width of the dam crest. For dam raises above 30 feet, the current dam crest length was maintained, but cross-sectional areas were used to calculate the incremental increases in concrete including the concrete required for a mass concrete overlay on the downstream face.

Dam raises utilizing concrete mass overlay utilized a range of downstream face slopes. Included within the 1998 Reclamation Technical Memorandum are structural analyses showing that the maximum slope for the downstream face of an enlarged Shasta Dam is 0.7:1 (horizontal: vertical). For the purpose of this analysis, the maximum downstream face slope of 0.7:1 was used to assess the volume of concrete required for the enlargement of the dam with a concrete overlay. It is estimated that a dam raise of about 130 feet is the maximum height for which the existing dam toe would be maintained with a 0.7:1 downstream slope. Dam raises greater than 130 feet would likely require the relocation of the dam toe in order to maintain a downstream slope of 0.7:1. Dam raises less than 130 feet would involve a downstream slope varying from the existing 0.8:1 to the maximum slope of 0.7:1.

As the height of Shasta Dam increases, wing dams would be required to extend the dam crest beyond its existing length. The 1998 Reclamation Technical Memorandum included reinforced earth embankments for the wing dams in the estimate for a 6.5-foot raise. Reinforced earth embankment wing dams are estimated to be acceptable for dam raises up to 30 feet. Any dam raise requiring a mass concrete overlay on the downstream dam face (above 30 feet) would require the construction of roller-compacted concrete (RCC) wing dams on each abutment. For the RCC wing dams, a downstream face of 0.8:1 was used for all dam heights. This uniformity makes the cross-sectional area trapezoidal with dimensions of a consistent ratio. The length of the crest for the section was estimated to represent the length of the entire section of wing dam. The crest length expanded linearly from a minimum length increase of 1,080 feet for a 30-foot raise, to 2,210 feet for a 200-foot dam raise.

Other items tied to the volume of concrete used were concrete in slip-formed facing elements, cement, pozzolan, concrete temperature control apparatus, and reinforcing bars. The quantity of material used for each of these items was proportioned according to the volume of concrete used. Based on available information, some constant costs were estimated for all heights above 30 feet, including the dental concrete, concrete used for crest features, the left side gantry crane, and ventilation systems. Other items, such as the right side gantry crane, are required for all heights.

It is estimated that the rate of the increase of the cost of the concrete accelerates for raises greater than 130 feet, due to the relocation of the dam toe. For dam raises less than 130 feet, a 5-foot increase in dam height requires approximately 80,000 cubic-yards of additional concrete, whereas above 130 feet, a 5-foot increase in height requires more than 160,000 cubic-yards of additional concrete. **Figure 3** shows the field costs associated with the concrete dam and required wing dams. In **Figure 3**, as in all of the cost curves in this section, the “other” category in the plots is a compilation of miscellaneous, low-cost items.

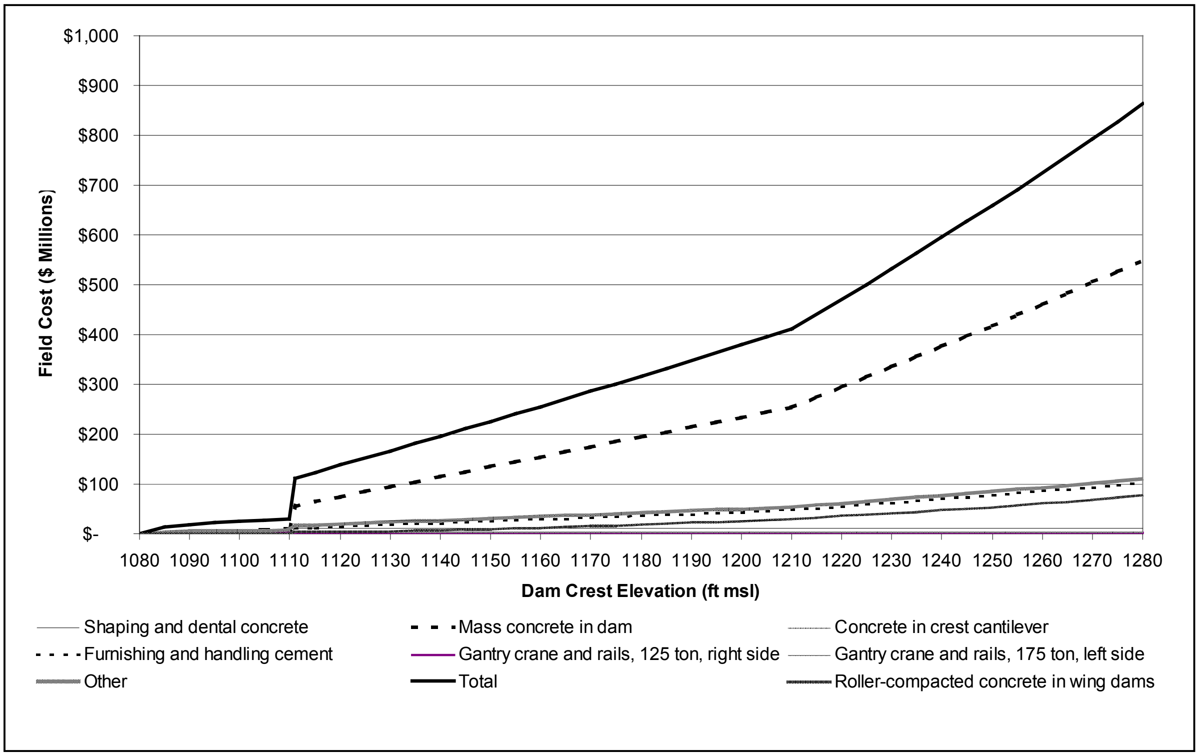


Figure 3 – Field Costs Associated with Concrete Dam and Wing Dams

DAM CREST STRUCTURE REMOVAL

Prior to any enlargement of Shasta Dam, existing structures on the dam crest would need to be removed. These structures include the gantry crane, the existing spillway drum gates, the spillway bridge, and concrete in the spillway crest and abutments.

The cost for the removal of the structures is a small portion of the overall cost of the dam raise. The approximate cost for the removal of structures ranges from 10 percent of the total field cost for the 6.5-foot raise to less than 1 percent of the total field cost for the 100- and 200-foot raises. The most costly items for removal include the spillway drum gates, the concrete in the parapet and crest cantilever, and the removal of the concrete in the spillway training walls. The existing spillway drum gates would be replaced regardless of the extent of the dam raise. The break-point in the cost for the removal of dam crest structures occurs at a dam raise above 30 feet, when mass concrete would need to be placed on the downstream face of the dam instead of concrete blocks on the dam crest. Such a concrete overlay on the downstream face of the dam would increase the amount of concrete removed from the parapets and crest cantilever, the spillway training walls, the stilling basin, and the left abutment core wall during embankment excavation, as well as require the removal of the freight and passenger elevators. In addition to the spillway drum gates and frames, training walls, and parapet and crest cantilever, there are several other miscellaneous items. They include, but are not limited to, removal of gantry crane and rails, removal of freight and passenger elevators, removal of concrete in spillway bridge and piers, and removal of miscellaneous concrete on both abutments. **Figure 4** shows the field costs associated with the removal of dam crest structures.

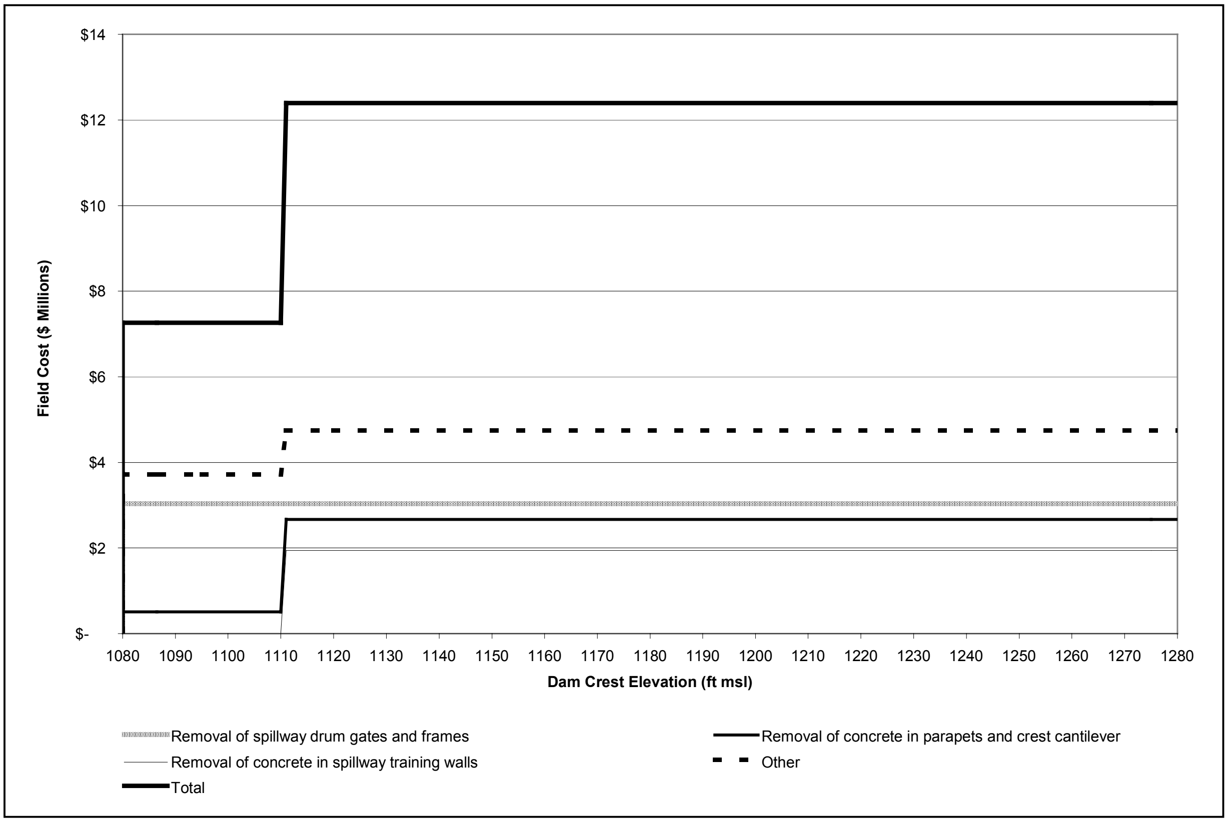


Figure 4 – Field Costs Associated with the Removal of Dam Crest Structures

COFFERDAMS FOR LEFT AND RIGHT ABUTMENTS

As mentioned, a dam raise requiring a mass concrete overlay on the downstream dam face (above about 30 feet) would require the construction of roller-compacted concrete (RCC) wing dams on each abutment to extend the dam crest beyond its existing length. Construction of concrete wing dams requires the construction of upstream cellular cofferdams for the protection of the excavation required for the wing dam construction. Since the foundation excavation for the RCC wing dams would be the same regardless of the dam raise height, all required cofferdams would be the same size. Dam raises using a mass concrete block on the dam crest will not require concrete wing dams or the accompanying cofferdams.

The left abutment cofferdam would consist of four large cloverleaf cells founded on an excavated bench at elevation 973 feet msl. The right abutment cofferdam would consist of four small circular cells founded on an excavated bench at elevation 1,023 feet msl. The cells would consist of interlocking steel sheet piling back-filled with a free-draining sand and gravel material, extending to the existing dam crest at elevation 1,080 feet msl. Concrete would be placed at the contacts with the existing dam and abutments to provide water barriers. An average drawdown level at elevation 1,013 feet msl has been approximated for construction of all other diversion features. The most costly items related to constructing cofferdams for abutment protection are the sheet pilings. The cost for diversion and care of water during construction is also included in the cofferdam estimate.

The break-point for the cofferdams occurs for a dam raise above 30 feet. There is no cofferdam cost associated with concrete block dam raises to about 30 feet since RCC wing dams would not be required. All dam raises above 30 feet would require cofferdam construction. **Figure 5** shows the field costs associated with cofferdams for the left and right abutments.

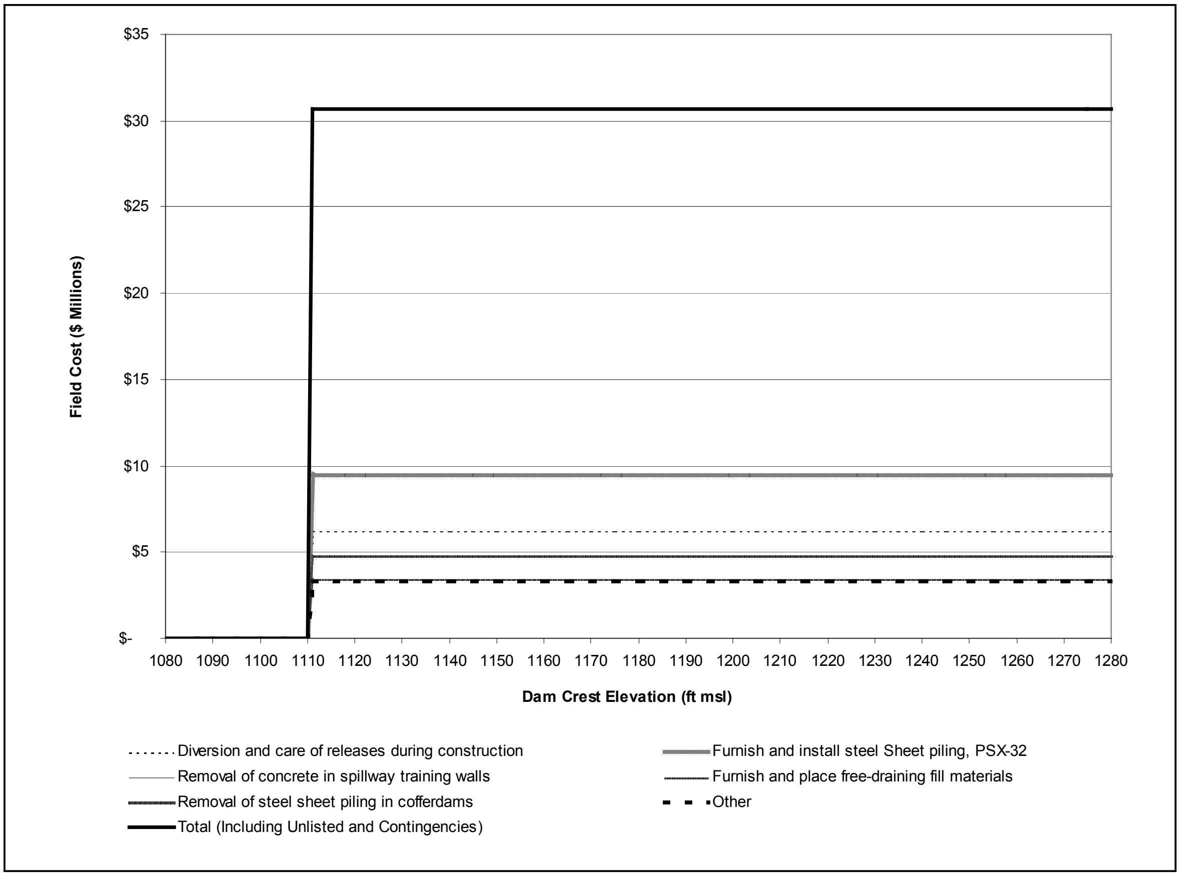


Figure 5 – Field Costs Associated with Cofferdams for Left and Right Abutments

SPILLWAY MODIFICATIONS

For this analysis, the spillway was separated from the concrete for the dam embankment due to the number of appurtenances required in spillway construction. When the downstream face of the dam is affected, the mass concrete used for the actual spillway construction is included in the concrete dam section. Otherwise, the costs of the spillway construction and for the training walls, gates, gate hoists, and stilling basin are included in this analysis.

The replacement of the existing drum gates with radial gates was identified as an essential aspect of any dam enlargement in the 1998 Reclamation Technical Memorandum, so costs associated with the spillway gate replacement are included with all dam raise options. The major height-dependant features related to the spillway are the training walls. With each dam raise, the downstream face of the dam is elongated, resulting in longer walls. The dimensions of the training walls used in the 1998 analysis are 30 feet high and 3 feet wide for all raises, so the length of the wall is the only variable associated with dam height. With the increased concrete used in lengthening the walls, there is an additional need for cement, pozzolan, and reinforcing bars.

In addition to the work done on the dam itself, the stilling basin at the base of the spillway is enlarged for the 200-foot raise in the 1998 Technical Memorandum. Since the stilling basin is not enlarged for the 100-foot raise option, it is estimated that the stilling basin is only affected by dam raises over 100 feet that correspond to relocating the toe of the dam. Raises requiring a change in the location of the dam toe would also require a modification of the stilling basin, and the relocation expense required is constant for all dam raises over 130 feet.

The costs associated with the replacement of the drum gates are the most expensive spillway-related cost. These costs are uniform and are required for any magnitude of dam raise, so they are not associated with a break-point. There are two break-points in the costs associated with the spillway. The first break-point is related to where the spillway crest concrete cost is accounted for. It occurs at the elevation where the dam raise approach changes from the mass concrete blocks on the crest to enhancing the downstream face of the dam, which is above 30 feet. The spillway cost for dam raises using concrete blocks confined to the crest includes the cost for building the spillway crest, whereas that cost is included with the mass concrete cost for the concrete overlay. The second break-point associated with the spillway is above a dam raise of 130 feet, where toe of the dam is extended (in order to maintain the downstream face slope requirements) and the stilling basin requires replacement. **Figure 6** shows the field costs associated with spillway modifications.

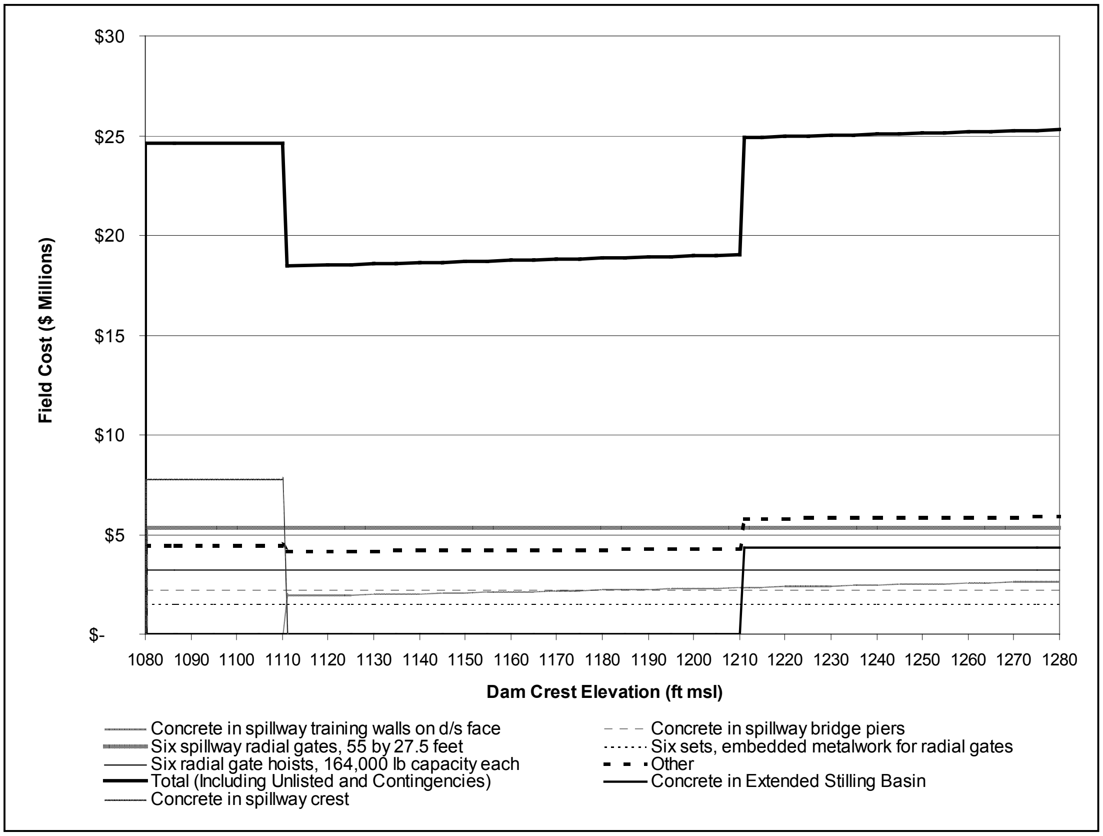


Figure 6 – Field Costs Associated with Spillway Modifications

RIVER OUTLET MODIFICATIONS

The river outlet cost analysis includes the costs for the replacement of the gates on the upstream face of the dam controlling non-gated-spillway flood releases. Shasta Dam has 18 outlets in three tiers. There are six 96-inch outlets at elevation 940.4 feet msl (invert of upper tier), eight 96-inch outlets at elevation 840.4 feet msl (invert of middle tier), and four 102-inch outlets at 740.4 feet msl (invert of lower tier). Any dam raise would require the replacement of the lower tier tube valves on the 102-inch outlet valves due to problems with vibration during certain operating conditions. New gates on the lower tier outlets would also provide increased operating reliability and improved discharge capacity. The 1998 Reclamation Technical Memorandum indicates that the 96-inch gates at 840.4 feet msl would require replacement with a 100-foot raise, and all of the gates would require replacement for a 200-foot raise. Current estimates indicate that the middle tier of 96-inch gates is adequate for raises up to 30 feet. The middle tier gates would be replaced for raises over 30 feet. The upper tier gates would be replaced for raises over 130 feet.

The itemized costs used in the 1998 Reclamation Technical Memorandum included the costs for replacement of the gates and other associated items as a function of their weight. Using the information from the 100-foot and 200-foot raises, relationships for the number of gates and their individual costs were developed, and this information was used to develop the itemized costs for the break-point analysis. It is estimated that all other replacements and outlet changes related to dam raises greater than about 130 feet are the same with the exception of the amount of cement, pozzolan, and re-bar required for the additional gate replacements necessitated by dam raises over about 130 feet. It is estimated that the cumulative weight of the 36-inch steel piping for air vents is relative to the height of the dam. Further study is needed to evaluate the air venting requirements and necessary air vent replacements. Air vent modifications are estimated to be insignificant in the context of identifying major break-points.

The lower tier gates will require replacement for any dam raise, so they do not indicate a break-point. The middle tier of gates requires replacement above a 30-foot raise, and the upper tier of gates requires replacement above about a 130-foot raise. The dam raise heights corresponding to replacement of the middle and upper tier outlet gates represent significant break-points in cost. **Figure 7** shows the field costs associated with river outlet modifications.

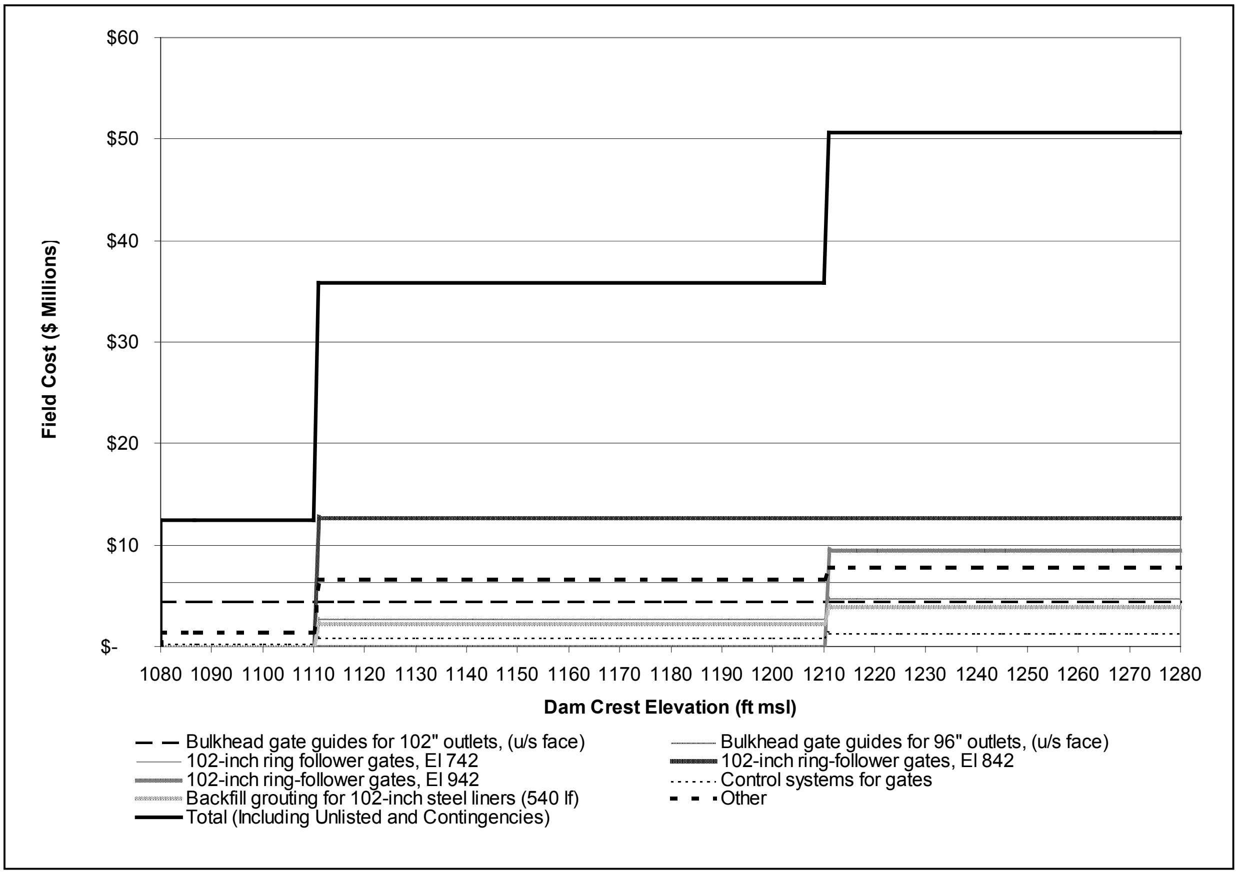


Figure 7 – Field Costs Associated with River Outlet Modifications

TEMPERATURE CONTROL DEVICE MODIFICATIONS

Construction of the Shasta Temperature Control Device (TCD) was completed in 1997. It is a multi-level water intake structure installed on the upstream face of Shasta Dam. The TCD is primarily a 250 foot tall steel shutter structure that allows operators to draw water from the top of the reservoir during the winter and spring when the surface water temperatures are cool, and from deep in the reservoir in the summer and fall when the surface water is warm. It has an operating range between 843 and 1,068 feet msl. It is also used to help improve oxygen and sediment levels in the river water and allows Reclamation to fulfill contractual obligations for both water delivery and power generation while benefiting salmon.

Modifications to the TCD would be needed for dam and top of joint use elevation raises above about 2 to 3 feet. The minimum modifications would primarily include raising the TCD operating equipment including gate hoists, electrical equipment, miscellaneous metalwork, and hoist platform above the new top of joint use elevation and lengthening the connections to the penstock intake structures. It is estimated that the initial cost for the modifications would be nearly $10 million and increase generally linearly as the height of dam raise (and increase in joint pool elevation) increases to about 100 feet. Based on design estimates in the 1998 Reclamation Technical Memorandum, it is estimated that the extent of modifications required to the TCD for dam raises of over 100 feet would be about the same. **Figure 8** shows the estimated field costs associated with modifying the TCD for various raises in the height of Shasta Dam.

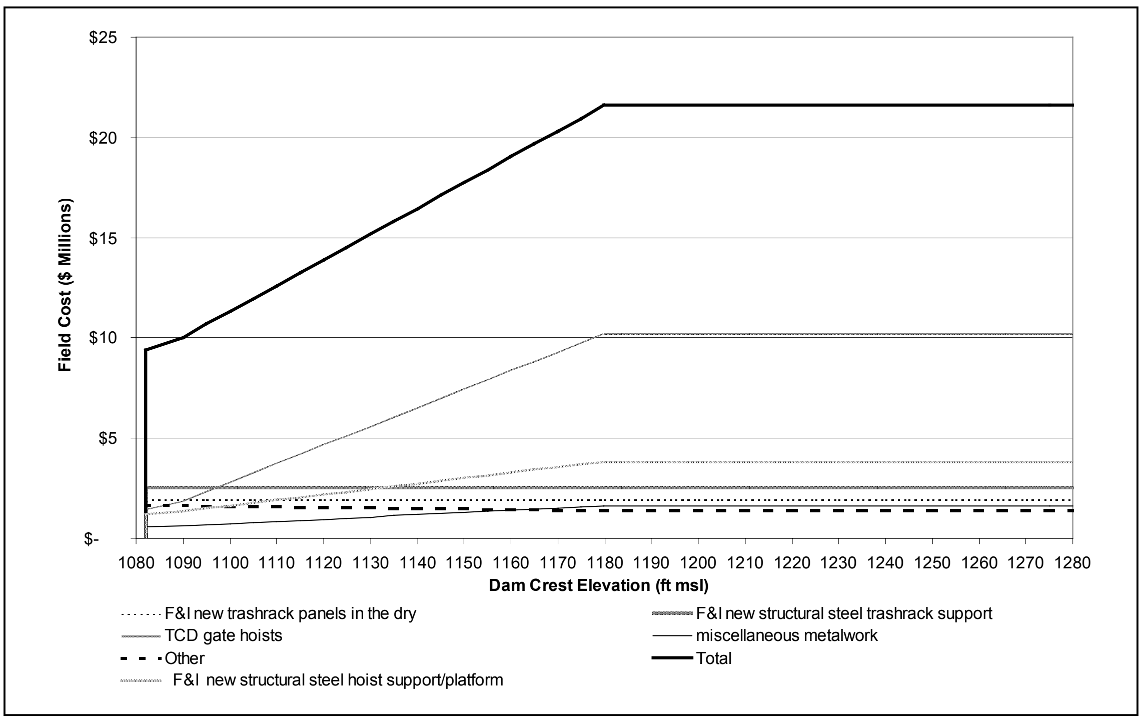


Figure 8 – Field Costs Associated with Modifications to the Existing TCD

As can be seen in **Figure 8**, there are no identified major break-points in cost for modifying the TCD above about a 2 to 3 feet dam raise. It should be noted, however, that at some dam raise probably less that about 100 feet, simply raising and lengthening the existing TCD structure would likely become infeasible and other modifications would be necessary. However, it is believed that the cost for the added modifications would likely not constitute a major break-point significant enough to change the overall conclusions of this office report.

PENSTOCK INTAKE MODIFICATIONS

It is estimated that the centerline of the existing penstock intakes would remain at the current level, but the gate hoists would require relocation with a higher dam crest. The existing gates, stop log guides, and hoists can be used for raises up to about 30 feet, but would need to be replaced with greater raises. Also, the stairway between the gate hoist structures and the gallery at elevation 1,068 feet msl would be plugged with concrete to seal the interior of the dam against higher reservoir elevations. Linear relationships between quantities of reinforced concrete, reinforcing, and cement were developed from the 1998 Reclamation estimates and used to interpolate costs for the raise options between 30 feet and 200 feet. Similarly, a linear relationship of the cost of the stop logs and its appurtenances with the height of the dam raise was used to estimate costs for the intermediate heights.

It is estimated that the break-point for modification of the penstock intakes would occur with a dam raise above about 30 to 50 feet, where the existing gates, stop log guides, and hoists would need to be replaced. Above that level, the increase in cost is linear and is related to the amount of concrete and reinforcing required. **Figure 9** shows the field costs associated with penstock intake modifications. For this office report, the cost break-point was estimated with a dam raise above 30 feet.

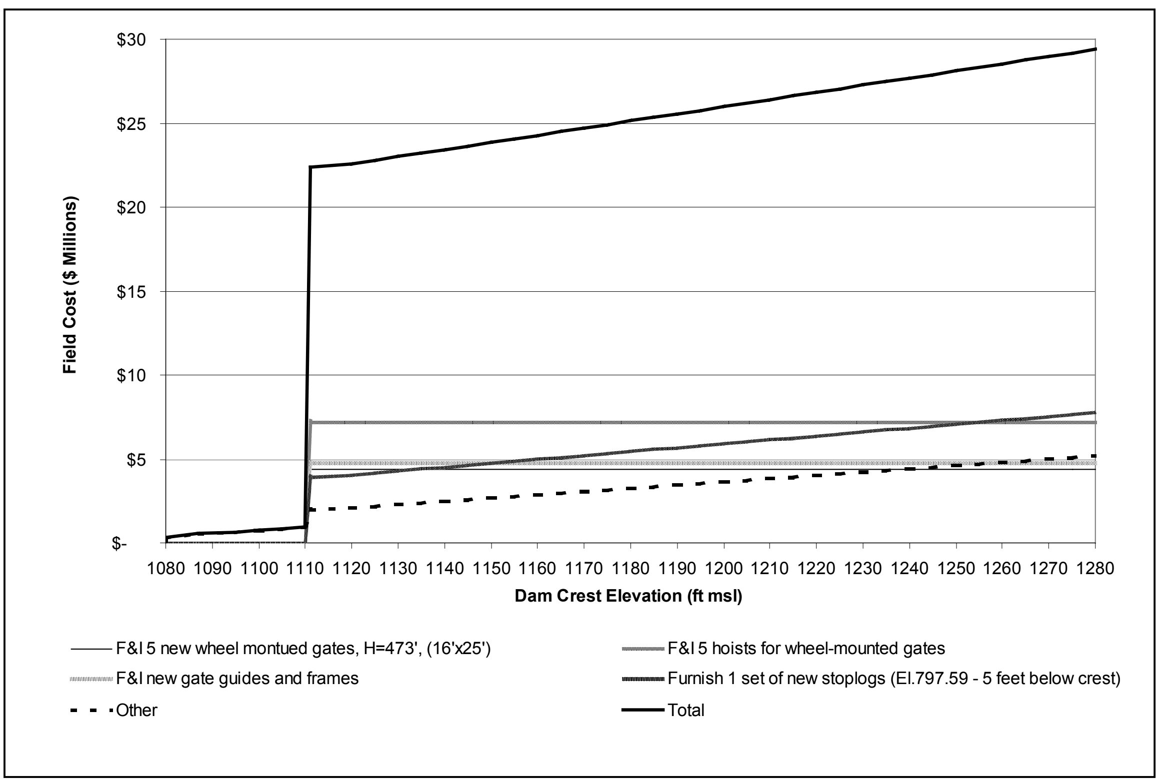


Figure 9 – Field Costs Associated with Penstock Intake Modifications

PENSTOCK MODIFICATIONS

It is estimated that portions of the 15-foot diameter steel penstock embedded within the dam would need to be replaced with new, thicker pipes for dam raises above between 30 to 50 feet. This is due to increased external hydrostatic pressures should the penstocks become de-watered. Replacement would require excavation within the dam to provide an oversized opening for installation and encasement of the new penstocks. The existing penstock centerlines would be maintained. Exposed portions of the penstocks are believed to be adequate for the increase in internal pressure. The existing pipes are adequate for static heads over 1,070. The existing supports would need to be strengthened for the maximum potential earthquake loads, and concrete saddle supports must be provided. It is believed that for raises above 100 feet, the scroll cases within the power plant are not adequate for the increased static internal pressure, necessitating a 15-foot-diameter butterfly isolation valve with associated filling lines and air valves in vaults immediately upstream of the power plant.

For this office report, the first breakpoint for the penstock modification is above 30 feet, where the excavation and replacement of the penstocks through the dam embankment is required. The amount of pipe replaced within the dam embankment is constant, 1,250 linear-feet. The length of pipe required beyond that is a variable of the dam raise and the thickness of the embankment. For all raises above 100 feet, the butterfly isolation valve and appurtenances would be required.

The penstock costs for raises above or below 100 feet would be relatively consistent. The second break-point in the penstock cost curve is estimated to occur at a dam raise of about 100 feet. The primary reason for the jump in cost above 100 feet is the additional requirement for the isolation valve. The actual dam raise magnitude requiring the addition of the isolation valve may be higher than 100 feet, but without additional information, its addition at just above 100 feet is used as a conservative estimate. **Figure 10** shows the field costs associated with penstock modifications.

POWER PLANT MODIFICATIONS

The existing power plant is designed to operate for the current range of reservoir levels. It is estimated that the 5 main Francis-type turbines would be able to operate for increased heads for a dam raise of up to 100 feet with minimal modifications. The break-point for power plant modifications is estimated to occur for dam raises above about 100 feet, when the existing scroll cases would require replacement, and the turbines would require replacement. Dam raises lower than about 100 feet would require some modification to the existing generating system, but additional studies are needed to identify the specific modifications necessary. Further study is needed to determine whether a new power plant on the left abutment or major modifications to the existing power plant would be more cost effective for raises above 100 feet. Since the specific modifications are yet to be determined, no power plant costs are included in this analysis. The 1998 Reclamation Technical Memorandum included costs of over $300 million for a new power plant on the left abutment for the 100-foot and 200-foot raises instead of modifications to the existing power plant.

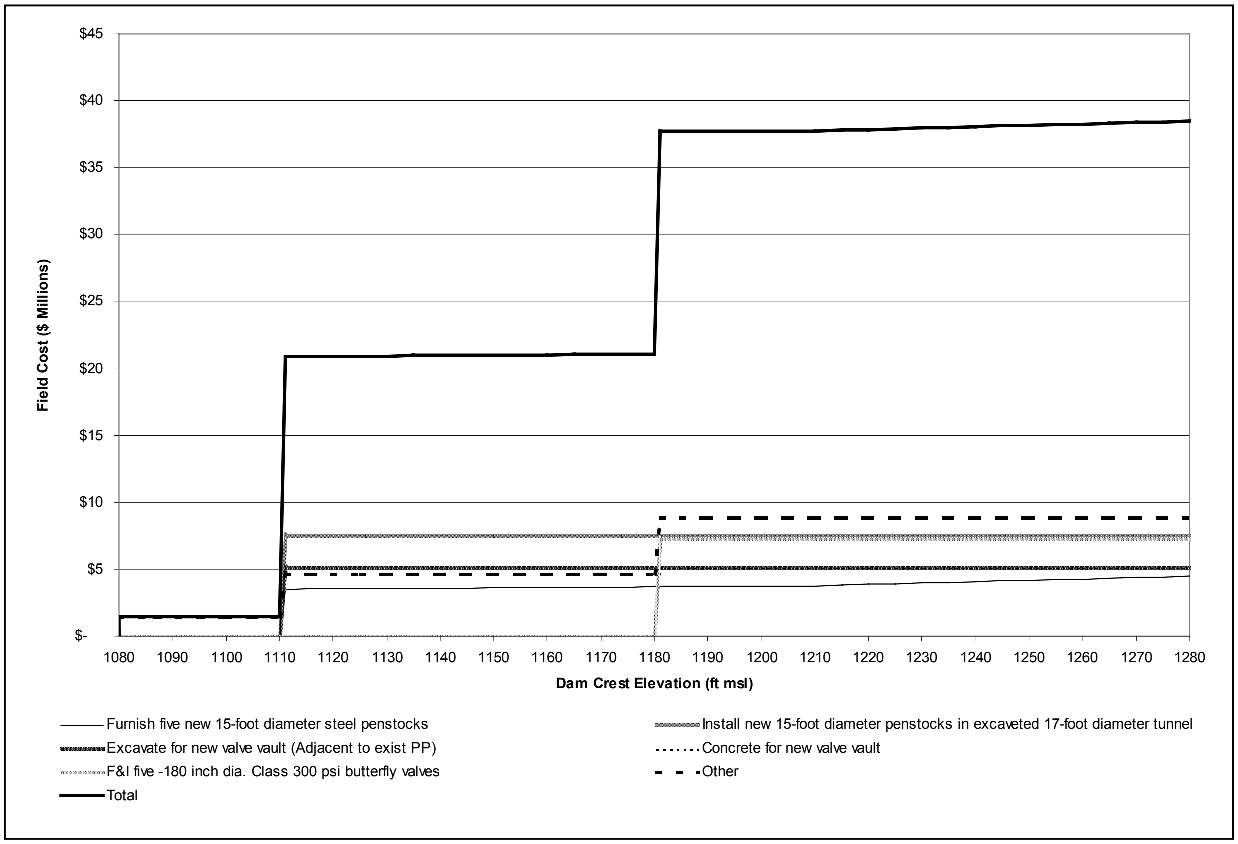


Figure 10 – Field Costs Associated with Penstock Modifications

COMBINED– SHASTA DAM AND APPURTENANCES

Figure 11 is a compilation of all the cost curves presented in this chapter. This curve is not intended to represent the overall total cost for raising Shasta Dam (for example, power plant modification costs are not included), but is intended to reflect the locations of significant break-points in the costs of raising the dam.

As shown in **Figure 11**, the first main break-point is estimated to occur at a dam raise of about 30 feet. This break-point is primarily related to the point where the method of raising the main dam structure changes, the middle tier of outlet gates is replaced, cofferdams are required, and the penstocks within the dam are replaced. The cost of concrete required for the dam is the most significant and costly feature associated with enlarging Shasta Dam. The concrete costs increase linearly between a 30-foot and a 130-foot raise, and linearly from a 130-foot to a 200-foot raise. The second break-point in the combined dam curve occurs at a 100-foot raise, where isolation valves for the penstocks are required. The third break-point in the combined dam curve occurs at a 130-foot raise, where the upper tier of river outlet gates is replaced. The cost break-points discussed for other items are insignificant when compared to the overall costs for enlarging the dam. For raises below 30 feet, the costs of modifications to the spillway, TCD, and low tier of river outlets, and concrete for the main dam are the most significant cost components.

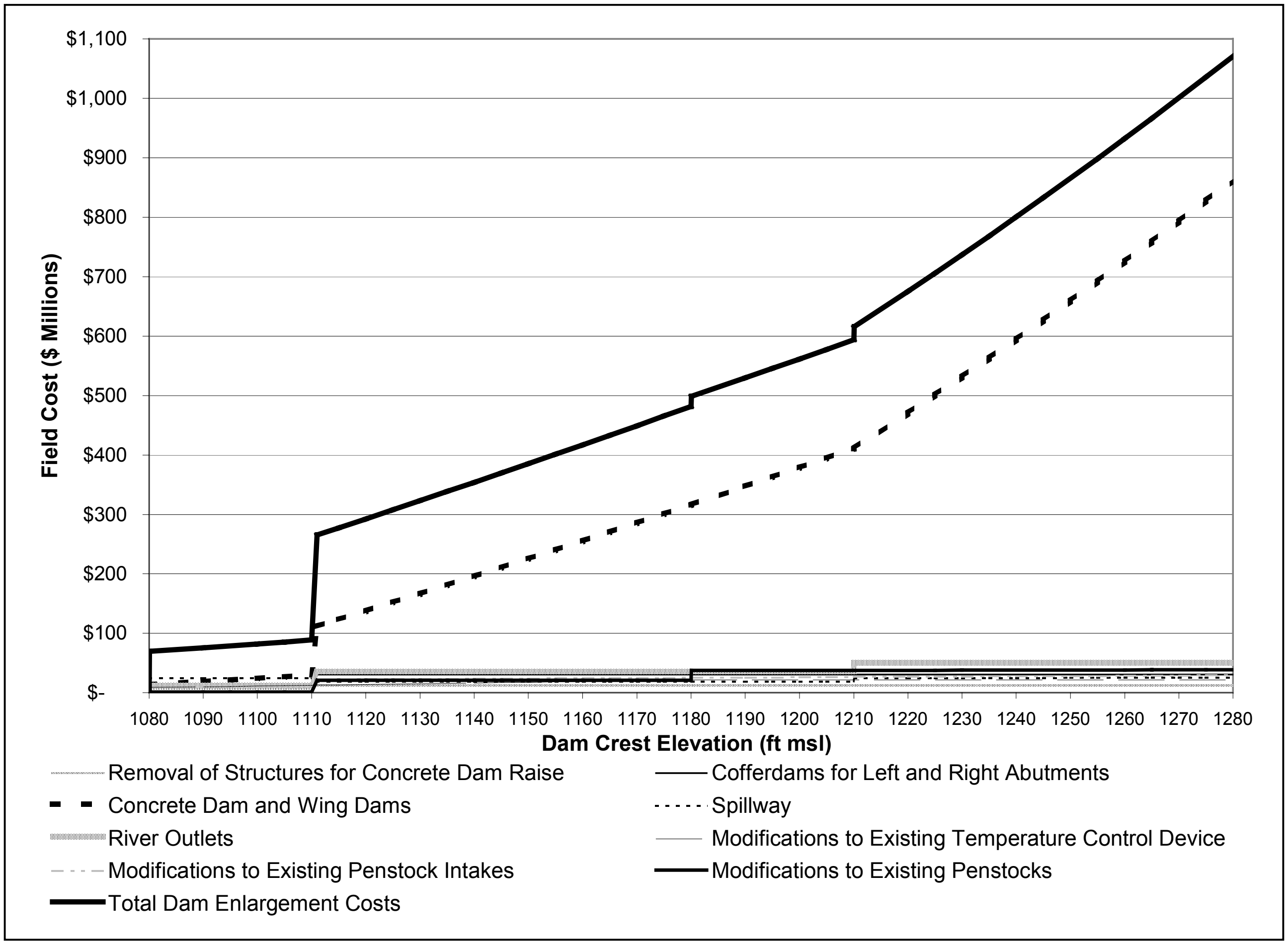


Figure 11 – Field Costs Associated with Raising Shasta Dam

CHAPTER V
SHASTA RESERVOIR AREA INFRASTRUCTURE

Following is a discussion of the major features within the Shasta Reservoir area associated with raising the joint use elevation of Shasta Reservoir up to an increase of 200 feet. Graphs of estimated field costs versus top of joint use (gross pool) elevation (field cost data in the previous chapter on the dam were plotted versus dam crest elevation) are also included to illustrate the costs of modifying various dam components. These items primarily include:

- Buildings
- Reservoir Bridges
- Reservoir Dikes
- Roads
- Railroad
- Other Facilities and Infrastructure

BUILDINGS

There is an estimated 630 buildings between the existing top of joint use (gross pool) elevation of Shasta Reservoir and elevation 1,280 feet msl. Based on a 2003 infrastructure inventory at Shasta Reservoir, there are about 200 buildings along the shoreline between the elevations of 1,070 and 1,100 feet msl. Buildings above 1,100 feet msl were not specifically inventoried in the 2003 effort. However, based on available aerial photos and U.S.G.S. quadrangle maps, there is an estimated 430 buildings between elevations 1,100 and 1,280 feet msl. Communities located between 1,070 and 1,280 feet msl include Sugarloaf, Lakeshore, Silverthorn, Delta, Pollock, Lakehead, and Riverview. Bridge Bay Resort and Marina is the largest resort and marina complex on Lake Shasta, and one of the largest inland marinas in the western United States. Several of the main buildings are located within a few feet of the joint use pool elevation, and the resort would be entirely inundated with a 200-foot dam raise. **Figure 12** shows the estimated number of buildings that could be impacted with dam raises up to 200 feet. The solid lines in the figure represent buildings from the 2003 inventory. The dotted lines in the figure represent estimated numbers of buildings. The types of buildings are split up into residential (cottages, homes, etc.), commercial (resorts, marinas, stores, etc.), and U.S. Forest Service sites (stations, campground buildings, recreation site restrooms, etc.).

Figure 13 shows the estimated total cost to relocate, replace, or abandon the impacted buildings as a function of the top of joint use elevation. On the basis of the 2003 inventory, the average square feet per structure is about 1,785. The graph in **Figure 13** is based on a relocation or replacement requirement of a structure when the top of joint use water surface would equal the lowest ground elevation at the building, and a unit relocation cost of $100 per square foot. For the estimated portion of the total buildings curve (above 1,100 feet msl) in **Figure 12**, the number of buildings at each elevation increment was multiplied by the average square feet per building to get the total square feet impacted, then the unit relocation cost was applied to calculate the total relocation cost in the portion of the **Figure 13** curve above 1,100 feet msl.

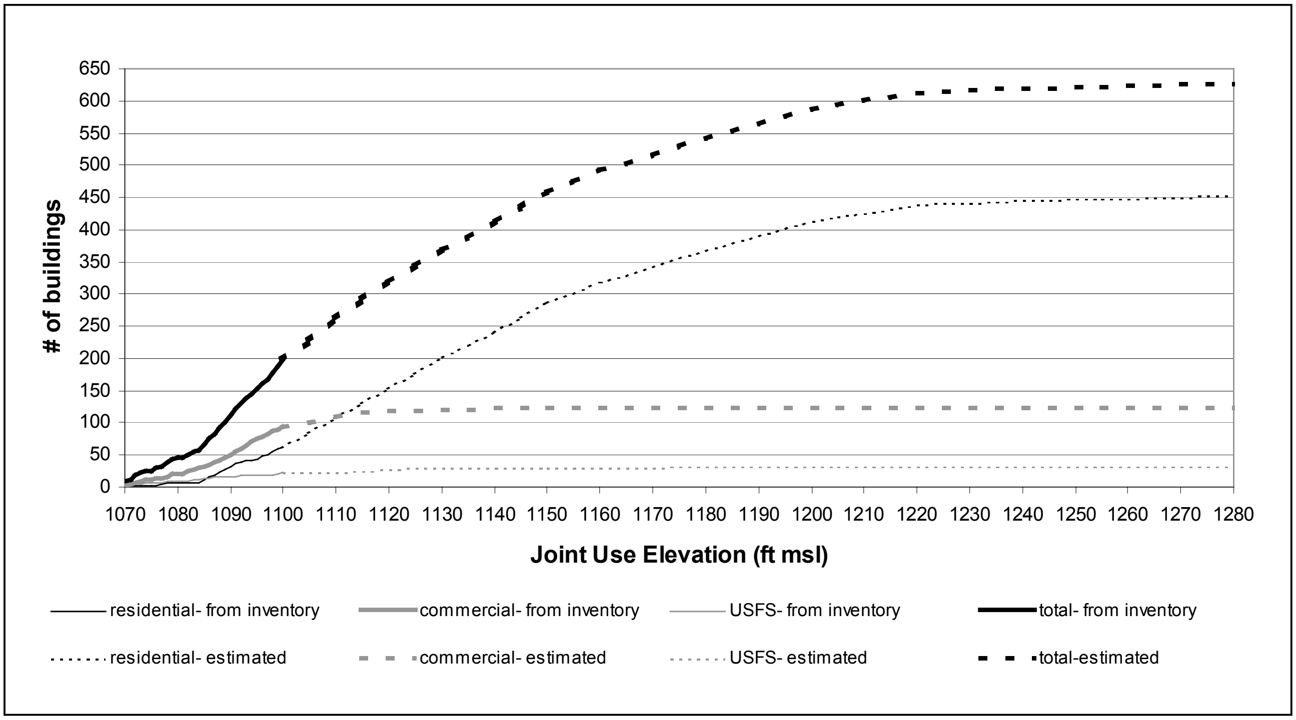


Figure 12 – Elevation vs. Number of Buildings Impacted

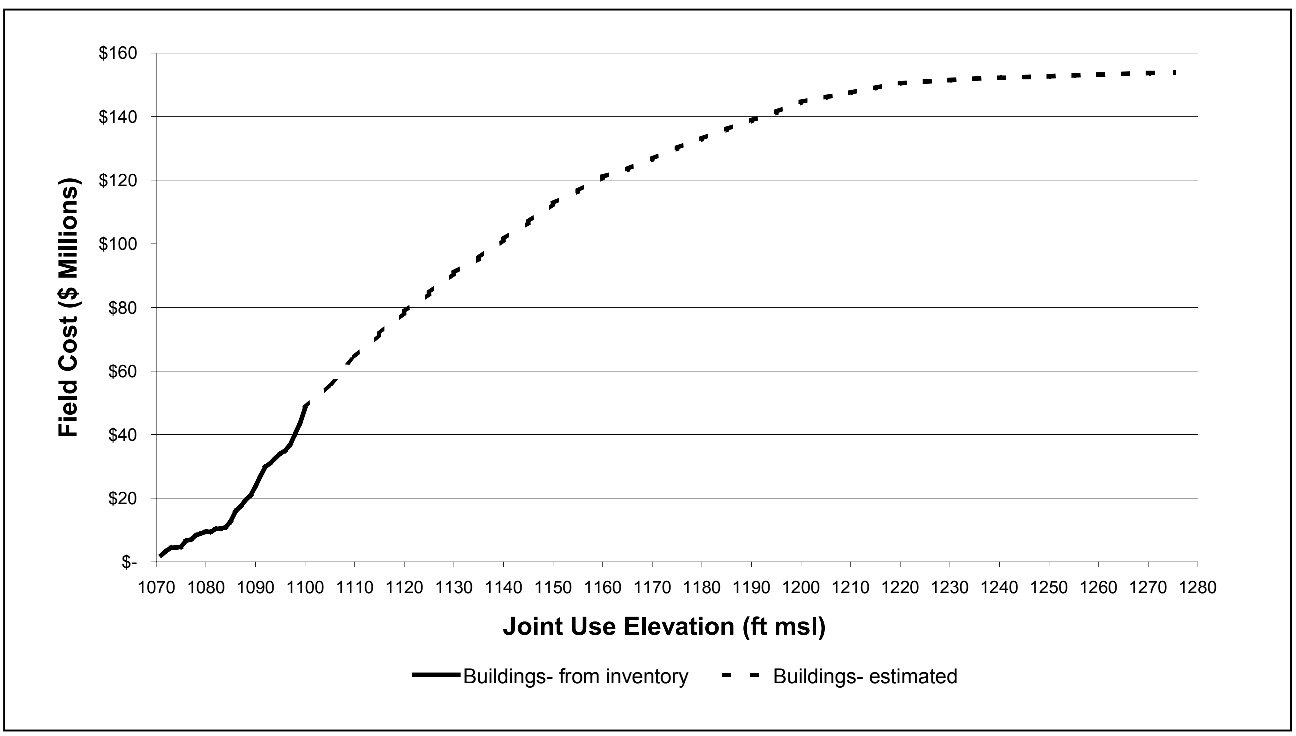


Figure 13 – Field Costs Associated with Building Relocations

The estimated unit replacement cost is intended to cover demolition and new construction. It should be noted that this does not account for all of the real estate costs associated with site acquisitions. However, because these costs are estimated to be incurred in a similar manner for each site, they would not be influential in determining the location of break-points in the cost curve for building relocations. Real estate issues will require significant additional effort in future studies. The compatibility of new development with the forest plan will also need to be addressed in future studies. As can be seen in **Figures 12 and 13,** no major break-points exist where the cost or number of buildings drastically increases at a specific elevation.

RESERVOIR BRIDGES

The 2003 inventory identified 22 bridges that cross Shasta Reservoir or one of its tributaries. Each bridge was analyzed to determine the water elevation at which it would need to be relocated or replaced. **Table 3** presents elevations and dimensions for the bridges, as well as the estimated water level at which each bridge would require relocation. The locations of these bridges are shown on **Plate 4**.

There are many factors that influence the need to relocate, replace, or otherwise remediate bridges resulting from increases in the top of joint use (gross pool) elevation. For this office report, a minimum freeboard was identified for railroad and vehicle traffic. Generally, however, for railroads, and based on correspondence from UPRR, it is estimated that relocation would be needed when the new top of joint use elevation encroached to within 4 feet below the main structural bridge beams. For other bridges it is estimated that the structure would need to be relocated when the top of joint use water level encroached to less than 1 foot below the low chord (Doney Creek and Charlie Creek bridges are special cases; current gross pool reservoir levels come within a few feet of the bridge decks). Relocation/replacement costs were assigned on a per square foot basis. Costs were estimated at $300 per square foot for all minor bridges, $500 per square foot for all UPRR bridges, and $500 per square foot for the Tunnel Gulch Viaduct (I-5).

Relocation of the Pit River Bridge is the largest break-point in the cost curve for raising Shasta Dam and Reservoir. The 1998 Reclamation Technical Service Center Memorandum estimated a new bridge over the Pit River would cost approximately $340 million. Future studies will be needed to assess modifications to the Pit River Bridge and resulting costs for any potential raise in the top of joint use elevation. The Pit River Bridge carries the UPRR on the lower deck and I-5 on the upper deck. The current top of joint use (gross pool) is at the top of concrete on Pier 3 (see **Plate 3**). The top of concrete on Pier 4 is 1,072.2 feet msl. From the existing top of joint use to elevation 1,090.2, the bridge superstructure (bearings and trusses) at Piers 3 and 4 would need to be protected from inundation by some type of enclosure. The Pit River Bridge would need to be relocated above 1,090.2 feet msl, which is 0.5 feet below the lip of Abutment 2 at the south end of the bridge and 4 feet below the bottom of the main bridge beams at Abutment 2. A water surface of 1,090.2, which is an increase of 20.5 feet in joint use elevation, would provide approximately 13.3 feet of clearance below the north end of the bridge between Piers 6 and 7 (span 9). Providing 20 feet of clearance for houseboats would reduce the allowable joint use pool raise to about 13.8 feet. The U.S. Coast Guard has guidelines for navigational clearances, so they should be contacted and consulted with to ensure that the proper clearances are provided, since they may differ from current estimates.

TABLE 3
SUMMARY OF RESERVOIR BRIDGE INFORMATION[1]

Bridge Name	Agency	Inventory ID#[2]	Deck Elevation[3] (ft msl)	Low Chord[4] (ft msl)	Length (ft)	Width (ft)	Relocate Above Water Elev (ft msl)	Max Joint Use Raise[5] (ft)
Charlie Creek Bridge	Shasta Co.	98	1,073	~1,054	390	24	1,070	<1[6]
Doney Creek Bridge	Shasta Co.	108	1,075	~1,060	510	25	1,070	<1[6]
Doney Creek Bridge	Union Pacific	107	1,102-1,103	1,071	620	16	1,071	1
Sacramento River Bridge, 2nd Crossing	Union Pacific	97	1,107-1,112	1,071	1,040	17	1,071	1
Antlers Bridge	Caltrans	104	1,105-1,150	1,086	1,350	61	1,071	1
Didallas Creek Bridge	USFS	63	1,079	~1,074	50	12	1,073	3
McCloud River Bridge	USFS	142	1,079	~1,074	260	20	1,073	3
Second Creek Bridge	USFS	51	1,080	~1,075	20	12	1,074	4
Lakeshore Drive Overcrossing by Charlie Creek	Union Pacific	158	1,102	1,093	120	19	1,089	19
Pit River Bridge	Caltrans/ Union Pacific	33	1,156-1,171	1,094	3,590	52	1,090	20
Lakeshore Drive Overcrossing by Doney Creek	Union Pacific	263	1,103	~1,097	80	17	1,093	23
Wittawaket Creek Bridge	private	147	1,101	~1,096	50	10	1,095	25
Sacramento River Bridge, 3rd Crossing	Union Pacific	133	1,136-1,139	1,099	760	17	1,095	25
Interstate 5 Overpass	Union Pacific	159	1,109	~1,100	290	31	1,096	26
Squaw Creek Bridge	Shasta Co.	308	1,105	1,099	110	20	1,098	28
Sacramento River Bridge, 4th Crossing	Union Pacific	136	1,125-1,126	1,112	310	19	1,108	38
Dog Creek Bridge	Union Pacific	139	1,122	~1,113	180	18	1,109	39
Salt Creek Bridge	Union Pacific	67	1,151-1,156	1,114	1,430	17	1,110	40
Fender Ferry Bridge (Sacramento River)	USFS	195	1,120	1,115	310	12	1,114	44
Fender Ferry Bridge (Pit River)	USFS	65	1,142	~1,136	310	18	1,135	65
Tunnel Gulch Viaduct	Caltrans	321	1,152-1,172	~1,146	580	40	1,142	72
O'Brien Creek Bridge	Union Pacific	60	1,187-1,191	1,146	930	16	1,142	72

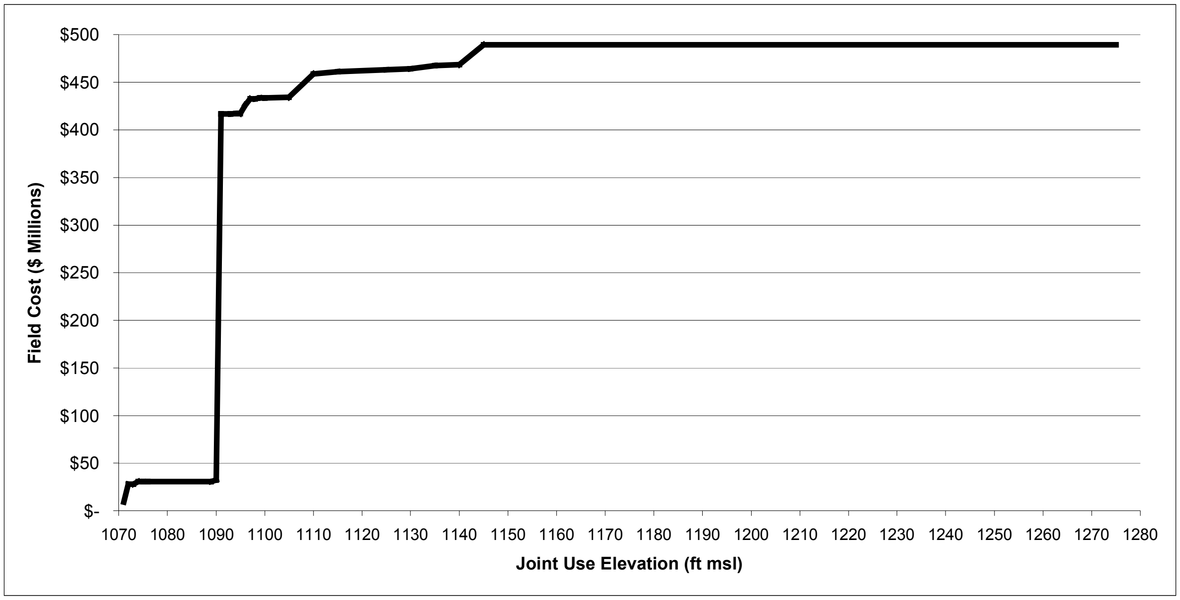
Notes:
1. *Most bridges would require some amount of remediation for any raise in top of joint use elevation.*
2. *Inventory Item ID# from the 2003 Reclamation Shasta Reservoir Area Inventory.*
3. *The elevation (or range in elevation) of the road or railroad surface.*
4. *Bottom of main horizontal bridge beams (varies for arch bridges).*
5. *Maximum raise in top of joint use elevation before a major relocation or replacement of bridge is required.*
6. *Charlie and Doney Creek Bridges are estimated to be relocated with any raise in top of joint use elevation.*

The Antlers Bridge carries I-5 across the Sacramento River. The current top of joint use (gross pool) elevation is at the top of concrete of the northern-most pier. The Antlers Bridge has a complex steel superstructure with a history of fatigue and safety issues. It was designed by Caltrans and is considered a "fracture critical" bridge, which means that it is subject to partial or complete collapse if one of the "fracture critical" structural members should fail. Replacement of the Antlers Bridge is in the Caltrans long-lead plans. The Antlers Bridge would need to be replaced or relocated with any raise in the joint use elevation of Shasta Reservoir. Replacement of the Antlers Bridge will occur with or without a raise in Shasta Dam, so the cost for replacing Antlers Bridge will be included in the without-project condition, and is not included in this break-point analysis. The current Caltrans preliminary design for an Antlers Bridge replacement takes into account a 6 to 8-foot raise in reservoir level.

Other significant bridges that would need to be relocated with any raise in reservoir level are the UPRR Doney Creek Bridge and UPRR Sacramento River Bridge, Second Crossing. The current top of joint use level of Shasta Lake is 3 inches below the top of concrete on the lowest pier (Pier 1) of the UPRR Doney Creek Bridge, and 10 inches above the top of concrete on the lowest pier (Pier 5) of the UPRR Sacramento River Bridge, Second Crossing. The deck elevation of the UPRR Doney Creek Bridge is a minimum of 32 feet above the current top of joint use elevation, and the deck elevation of the UPRR Sacramento River Bridge, Second Crossing is a minimum of 37 feet above the current top of joint use elevation. It is estimated that these bridges, which were designed in the late 1930's, can be replaced with structures that will allow the current railroad elevations to remain unchanged. Future studies will address these railroad bridge relocations in more detail. The UPRR has several other bridges that would need to be relocated for higher raises in reservoir level, but the relocation levels for the remaining bridges are higher than the Pit River Bridge.

As shown in **Table 3**, significant numbers of bridge relocations are required with minor increases in the top of joint use elevation, and all of the main reservoir bridges would need to be relocated with a top of joint use raise of about 73 feet. However, with greater increases in top of joint use elevations, major railroad and/or roadway system relocation would also be required (see sections on major roads and railroad).

Figure 14 shows the field costs associated with reservoir bridge relocations. The large break-point in cost just above a raise in joint use elevation of 20 feet (1,090 feet msl) is due to the Pit River Bridge relocation. Significant additional effort is necessary to define the potential for mitigating the impacts of higher reservoir levels on the existing bridge structures.



Note: Plot does not include every bridge in the vicinity of the reservoir area, only those identified in the 2003 Shasta Reservoir Area Inventory. Plot also does not include the Antlers Bridge (included in without-project conditions).

Figure 14 – Field Costs Associated with Reservoir Bridge Relocations

RESERVOIR DIKES

New saddle dikes would be required at Centimundi, Bridge Bay, Jones Valley, and Clickapudi Cove if Shasta Dam were raised 200 feet. The locations of these dikes are shown on **Plate 5**. New saddle dikes would also be needed for smaller raises. Based on the existing topography, new saddle dikes are estimated to be required for top of joint use (gross pool) elevation increases as follows:

- Centimundi- 160-foot top of joint use raise (1,230 feet msl)
- Bridge Bay- 160-foot top of joint use raise (1,230 feet msl)
- Jones Valley- 50-foot top of joint use raise (1,120 feet msl)
- Clickapudi Cove- 100-foot top of joint use raise (1,170 feet msl)

The new dikes are estimated to be required when the new joint use elevation is within 10 to 15 feet below the lowest point in the reservoir rim area. Cost estimates for the new saddle dikes are based on estimates developed in the 1998 Technical Service Center Memorandum for the 100-foot and 200-foot dam raises. The costs of the dikes at the above elevations were estimated to be a percentage of the Reclamation estimated cost at the Intermediate or High Option raises.

Following is the rationale used to interpolate the estimated cost of the first increment of new dike. Incremental costs were interpolated.

- Cost of Centimundi Dike at 1,230 feet msl = 85 percent of cost at 1,280 feet msl
- Cost of Bridge Bay Dike at 1,230 feet msl = 85 percent of cost at 1,280 feet msl
- Cost of Jones Valley Dike at 1,120 feet msl = 85 percent of cost at 1,180 feet msl
- Cost of Clickapudi Dike at 1,170 feet msl = 95 percent of cost at 1,180 feet msl

Figure 15 shows the cost curves for the four reservoir dikes. The Jones Valley Dike would be the largest and most expensive of the four dikes, and would be required at the lowest elevation.

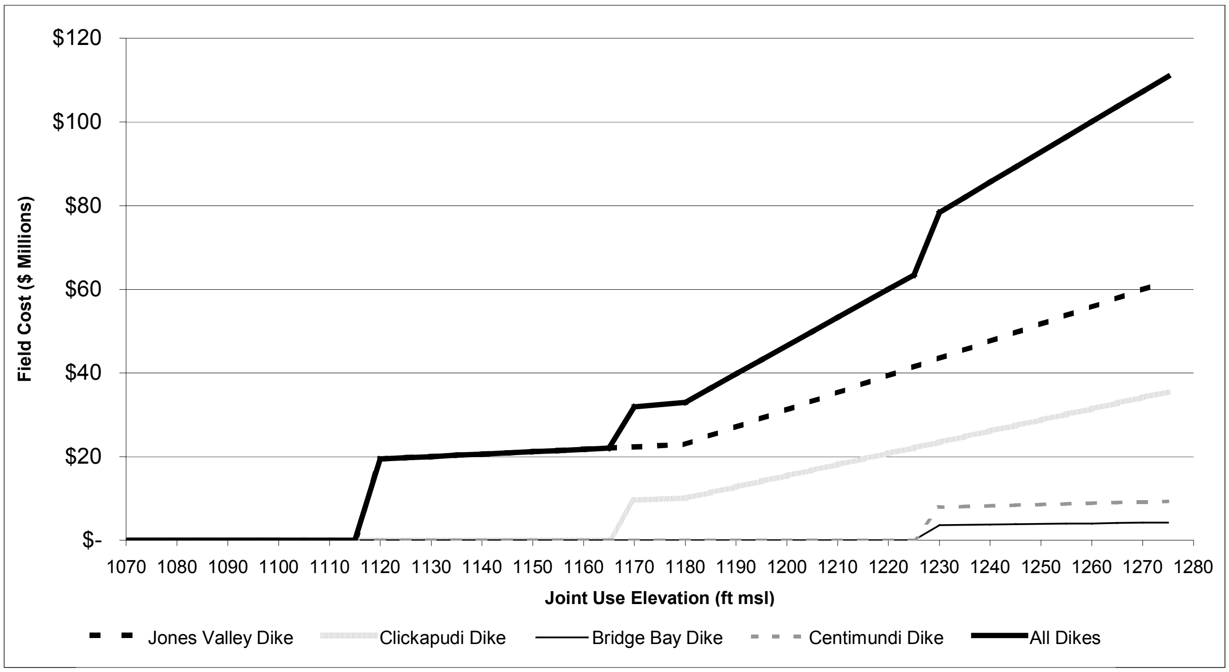


Figure 15 – Field Costs Associated with Reservoir Dikes

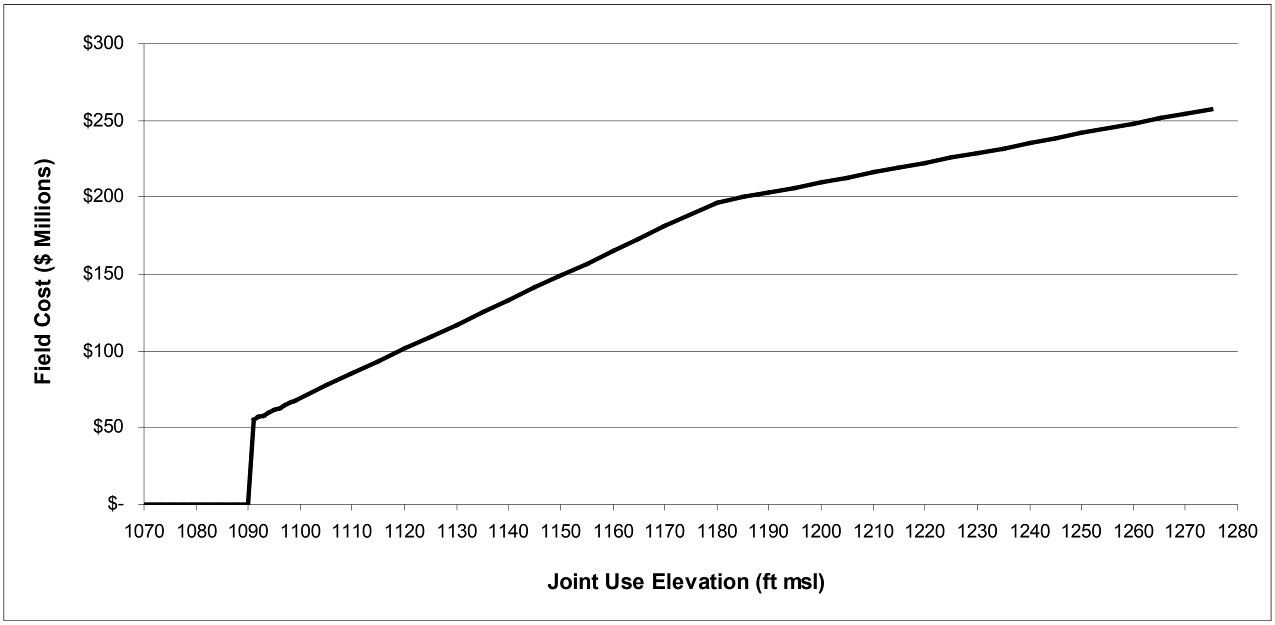
MAJOR ROADS

I-5 is the largest transportation route in the vicinity of Shasta Reservoir. The lowest portion of I-5 adjacent to the reservoir is located immediately north of the Antlers Bridge in the Antlers/Lakeshore area. This segment of I-5 has an elevation of about 1,084 feet msl. Protective dikes may be needed along the west side of this I-5 segment between the north end of Antlers Bridge and the south side of the UPRR embankment. Dikes may also be needed on the east side of the north approach of the Antlers Bridge to protect I-5 from water levels above about 1,080 and below about 1,090 feet msl. For raises in joint use elevation above 1,090 feet msl, this segment of roadway will require either protective dikes or relocation onto an elevated roadway segment.

The major roads (other than I-5) that would be impacted below 1,100 feet msl include Lakeshore Drive, Fenders Ferry Road, and Gilman Road. Lakeshore Drive connects residences, resorts, and recreation facilities in the Lakeshore and Sugarloaf areas. Fenders Ferry Road is one of the main forest roads in the northern area of Shasta Reservoir. Gilman Road provides access to the recreation facilities along the McCloud River Arm from I-5. The low segments of these roads would either need to be relocated outside of a raised joint use pool or abandoned. The costs associated with these roadway relocations would be a relatively linear function of increases to joint use pool elevation, and do not influence major break-points.

Cost estimates for relocating I-5 are based on estimates developed in the 1998 Technical Service Center Memorandum for the 100-foot and 200-foot dam raises. The costs of relocating I-5 at elevations below 1,180 feet msl (100-foot raise) were estimated to be percentages of the Reclamation estimated cost at the Intermediate Option raise. I-5 relocation costs are estimated to be incurred to the project at above a top of joint use elevation increase of 20 feet (1,090 feet msl). This is the estimated elevation of the major break-point for relocating I-5. The relocation cost for I-5 at this break-point was estimated to be 28 percent of the 1998 Reclamation cost to relocate I-5 at 1,180 feet msl. Incremental I-5 relocation costs were interpolated between, 1,091, 1,180, and 1,280 feet msl. **Figure 16** shows the field costs associated with the relocation of I-5.

It is estimated that replacement of the Antlers Bridge will occur with or without a raise in Shasta Dam. Accordingly, no cost will be included for replacing I-5 on the Antlers Bridge and approaches. The current Caltrans preliminary design for an Antlers Bridge replacement takes into account a 6 to 8-foot raise in reservoir level. A raise in reservoir levels of more than 6 to 8 feet may incur some additional cost to the with-project condition, but it is estimated that this cost will not be an influential factor in determining major break-points in the project cost. Future studies should analyze the cost effectiveness of protective dikes at the north end of the Antlers Bridge versus lengthening the Antlers Bridge to touch down north of the current low area of I-5.



Note: Plot does not include the portion of I-5 at the Antlers Bridge (included in without-project conditions).

Figure 16 – Field Costs Associated with Relocation of I-5

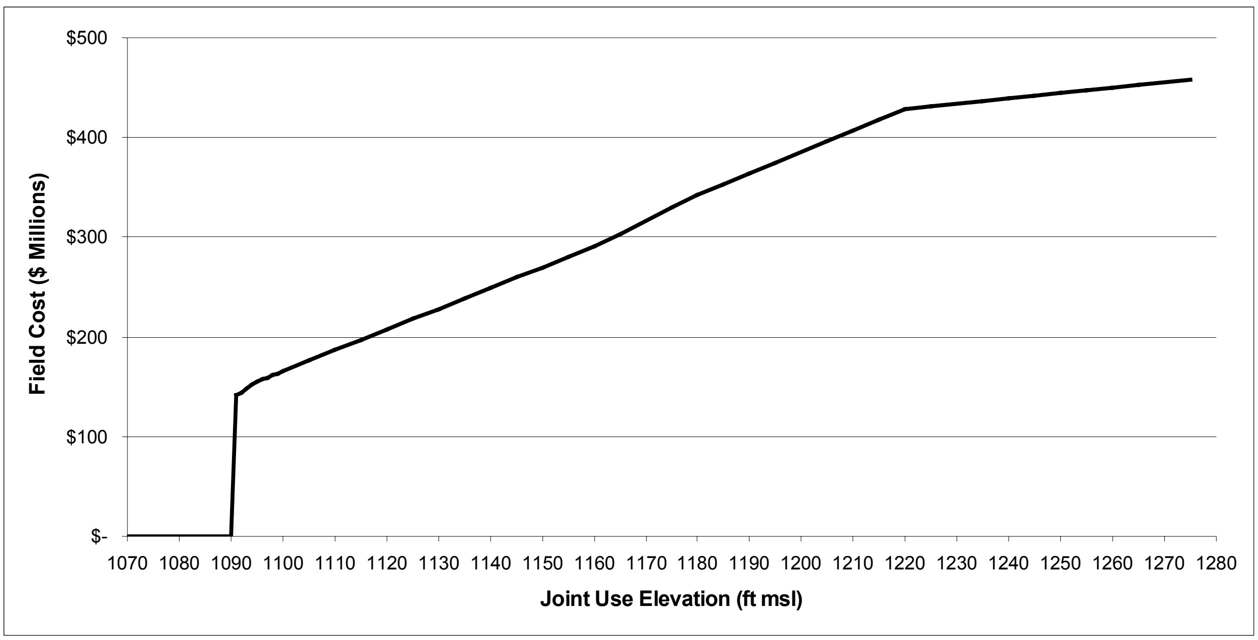
RAILROAD

The UPRR would be impacted starting at water surface elevations above 1,090 feet msl, when the Pit River Bridge would need to be relocated. The elevation of the railroad varies in the vicinity of Shasta Reservoir. It climbs up from 1,083 feet msl at the south end of Bridge Bay, to 1,220 feet msl near O'Brien, down to 1,100 feet msl just north of the Sacramento River Bridge, Second Crossing south of Lakeshore, up to 1,165 feet msl north of Antlers, then down to 1,120 feet at the Sacramento River Bridge, Fourth Crossing, then up to 1,140 at Delta, and then up to 1,270 at Lamoine. All of the railroad tracks adjacent to Shasta Reservoir would be inundated with a 200-foot raise of Shasta Dam. Relocating the railroad is a major cost, estimated in the 1998 Reclamation Technical Memorandum at $455 million for the 200-foot raise.

Approximately 0.6 miles south of the Pit River Bridge, the UPRR enters Tunnel 2. The 760-foot segment of railroad between Tunnels 1 and 2 ranges in elevation between 1,083 and 1,088 feet msl. A dike could be constructed to protect this segment of railroad. The dike would be required above approximately 1,078 feet msl, and could be built high enough to withstand reservoir levels up to 1,090.2 feet, at which point the Pit River Bridge would need to be relocated, requiring miles of railroad reconstruction.

Cost estimates for relocating the UPRR are based on estimates developed in the 1998 Reclamation Technical Service Center Memorandum for the 100-foot and 200-foot dam raises. The cost of relocating I-5 at the lowest elevation where some relocation is required was estimated based on percentages of the Reclamation estimated cost at the Intermediate Option raise. The relocation cost for the UPRR at 1,091 feet msl was estimated to be 55 percent of the earthwork and railroad cost and 20 percent of the bridges and tunnels cost from the 1998 estimated Reclamation cost to relocate the railroad at 1,180 feet msl. Relocation costs were interpolated between the cost control points.

Other railroad relocation break-points exist at the high and low points of the railroad within the reservoir vicinity (within the reservoir area, subgrade elevation increase and decrease from approximately 1,080, to 1,220, to 1,100, to 1,160, to 1,120, to 1,140, and to 1,270 feet msl). Most relocations are required between 1,100 and 1,220 feet msl. **Figure 17** shows the field costs associated with the relocation of the UPRR. The location of the break-point for the cost of relocating the UPRR is just above a 20-foot raise in joint use elevation, where the portion of railroad associated with the Pit River Bridge would need to be replaced. Increases in cost above this point are generally linear.



Note: Plot does not include costs for replacement of the 11 major railroad bridges (included in "Reservoir Bridges" section).

Figure 17 – Field Costs Associated with Relocation of UPRR

OTHER RESERVOIR AREA INFRASTRUCTURE

The Pit 7 Dam and Powerhouse are located at the east end of Shasta Reservoir on the upper Pit River (see **Plate 4**). The Pit 7 Dam is operated by Pacific Gas and Electric Company (PG&E). The normal tail water elevation downstream of the powerhouse is approximately 1,068 feet msl (NAVD 1988). The stilling basin lip 8.5 feet above existing joint use elevation, and the elevation of the wing walls to the existing stilling basin is 27 feet above the existing joint use elevation. The first major break-point for the Pit 7 facility would be when the expected increase in top of joint use elevation approaches the elevation of the power house yard floor at 1,106 feet msl. It is estimated that power could no longer be generated at the Pit 7 Dam above this point. No costs were developed for the subsequent loss in power generation capability or for relocation of the power house. The crest elevation of Pit 7 Dam is 1,278 feet msl, so the maximum water level with a 200-foot raise of Shasta Dam would come within a few feet of the crest of Pit 7 Dam. Further analysis is needed to quantify the impacts of a raise below 20 to 30 feet on Pit 7 Dam and Powerhouse. Potential impacts of low level raises of the Shasta Lake gross pool would primarily include (1) reduced hydropower generation during periods of elevated water surface elevations, (2) potential reductions in existing spillway capacities, and (3) added stresses to the side walls of the power plant.

In addition to the Pit 7 Dam and hydroelectric facilities, other primary reservoir area impacts in this break-point analysis include reservoir clearing and seepage mitigation. Reservoir clearing and seepage mitigation costs were taken from the 1998 Reclamation Technical Memorandum, and interpolated in between the Low, Intermediate, and High Options.

COMBINED– RESERVOIR AREA INFRASTRUCTURE

Table 4 is a summary of actions to be taken to address reservoir area infrastructure impacts. Estimates of impacts with increases in the top of joint use elevation from 1,070 to 1,100 feet msl were based on information in the Shasta Reservoir Area Inventory. Above 1,100 feet, less detailed information was available. **Table 4** is organized by top of joint use (gross pool) elevation, not dam crest elevation. This was done for simplicity in elevation references. In the 1999 Reclamation Appraisal Report, the amount of freeboard between the joint use elevation and the dam crest differs with alternate raises due to alternate spillway gate scenarios. For example, the Low Option dam raise is a 6.5-foot dam crest raise, which corresponds to a joint use elevation raise of 8.5 feet.

The combined cost curve for the all of the reservoir area infrastructure is shown in **Figure 18**. It includes relocation field costs for bridges, buildings and roads, UPRR, I-5, reservoir dikes, and reservoir clearing and seepage mitigation. **Figure 18** is not intended to represent the exact overall total cost of raising Shasta Reservoir levels on infrastructure in the reservoir area, but is intended to reflect the locations of significant break-points in the infrastructure-related costs of raising the reservoir.

TABLE 4
RESERVOIR INFRASTRUCTURE IMPACTS AND ACTIONS 1,070 - 1,280 FT MSL[1]

New Top of Joint Use Elevation	Impact Remediation Actions
1,071	Relocate Charlie Creek Bridge, Doney Creek Bridge, and Antlers Bridge, Relocate impacted portion of Lakeshore Drive north of Sugarloaf
1,072	Relocate UPRR Doney Creek Bridge, UPRR Sacramento River Bridge 2nd Crossing, Relocate segment of Bully Hill Rd impacted on Squaw Creek Arm
1,073	Relocate portion of Lakeshore Drive impacted by Charlie Creek Bridge
1,074	Relocate McCloud River Bridge and Didallas Creek Bridge, Relocate portion of Silverthorn Rd impacted on Pit River Arm
1,075	Relocate Second Creek Bridge
1,076	Relocate portion of Lakeshore Drive impacted by Doney Creek Bridge
1,077	Relocate portion of Conflict Point Rd impacted (on north side of Salt Creek)
1,078	Build embankment for UPRR at Bridge Bay
1,080	Build embankment for I-5 at Lakeshore, Relocate portion of Gilman Rd impacted near McCloud Bridge, and portion of Fender Ferry Rd impacted near McCloud Bridge
1,090	Relocate UPRR Lakeshore Drive Overcrossing by Charlie Creek
1,091	Relocate Pit River Bridge, Relocate UPRR Sacramento River Bridge, 2nd Crossing, Relocate portion of I-5 impacted by Lakeshore
1,094	Relocate UPRR Lakeshore Drive Overcrossing by Doney Creek
1,096	Relocate Wittawaket Creek Bridge and UPRR Sacramento River Bridge, 3rd Crossing
1,097	Relocate UPRR I-5 Overpass
1,099	Relocate Squaw Creek Bridge
1,100	Begin to remediate impacts to Silverthorn community (1,100 to 1,250)
1,105	Relocate portion of West Side Road impacted at Squaw Creek Bridge
1,106	Reservoir gross pool at top of powerhouse at Pit 7 Dam[2]
1,109	Relocate UPRR Sacramento River Bridge, 4th Crossing
1,110	Relocate UPRR Dog Creek Bridge
1,111	Relocate UPRR Salt Creek Bridge
1,114	Relocate Fender Ferry Bridge (Sacramento River near Delta)
1,134	Jones Valley Dike becomes necessary
1,135	Relocate Fender Ferry Bridge (upper Pit River)
1,143	Relocate Tunnel Gulch Viaduct on I-5, Relocate UPRR O'Brien Creek Bridge
1,150	Begin to remediate impacts to town of Delta (1,150 to 1,190)
1,165	Begin to remediate impacts town of Pollock (1,165 to ~1,220)
1,170	Begin to remediate impacts town of Lakehead (1,170 to ~1,220)
1,172	Relocate UPRR O'Brien Creek Bridge
1,180	Clickapudi Cove Dike becomes necessary
1,230	Bridge Bay and Centimundi Dikes become necessary
1,278	Reservoir gross pool at crest of Pit 7 Dam[2]

Notes:

1. *This table does not include impacts to specific buildings. Impacted portions of roads, communities, and other infrastructure will be relocated where possible. However, in some cases where relocation is not feasible, these facilities may need to be abandoned.*
2. *Specific remediation actions at the Pit 7 dam have not yet been determined. The approximate elevation at which the dam would need to be abandoned would likely be between 1,106 feet msl (powerhouse yard floor) and 1,278 feet msl (crest of dam), but further study is needed.*

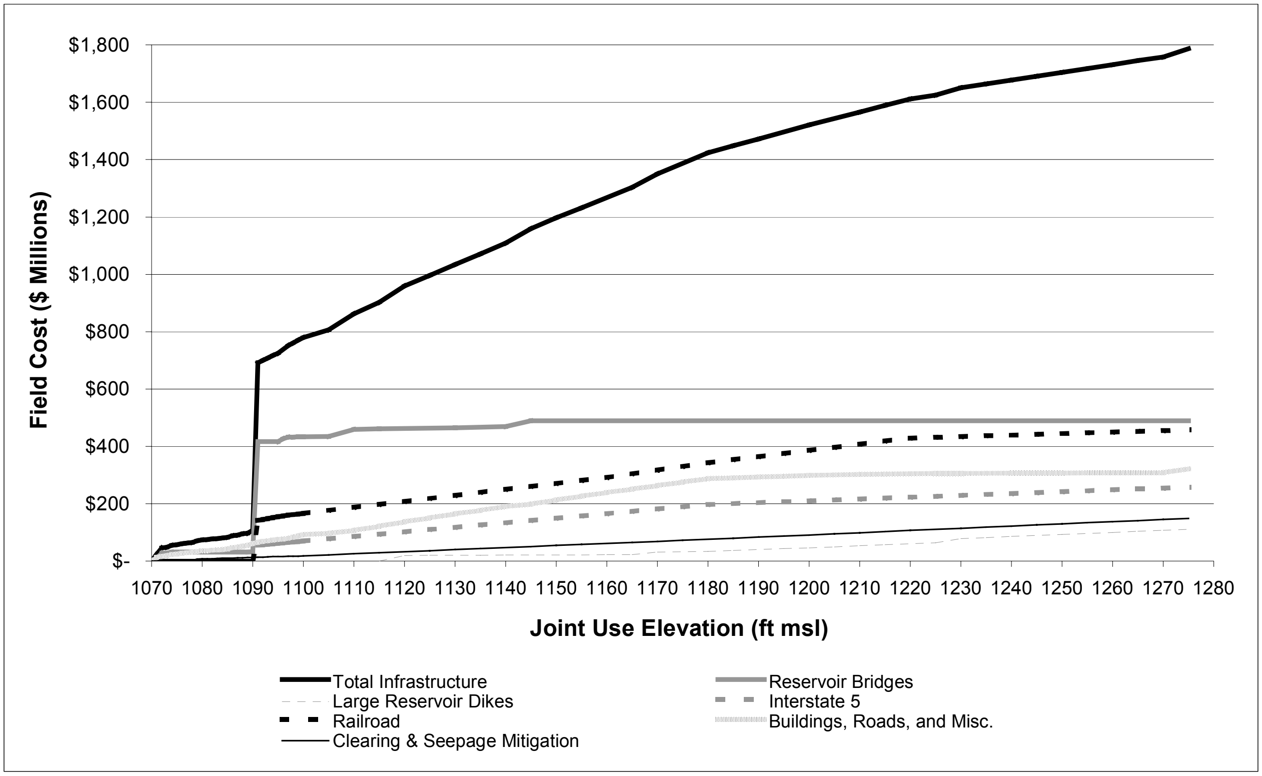


Figure 18 – Field Costs Associated with All Reservoir Area Infrastructure

The major break point in the total curve for reservoir area infrastructure on **Figure 18** occurs above a 20-foot raise in joint use elevation. This break-point correlates with the Pit River Bridge relocation; relocation costs for I-5 also start above a 20-foot raise in joint use elevation. The Pit River Bridge is the single largest break-point in cost for all of the reservoir area infrastructure. The other major cost components of the reservoir area infrastructure relocations are the UPRR, buildings and minor roads, and I-5, respectively. The large reservoir dikes and clearing and seepage mitigation account for only a very small fraction of the overall cost to relocate the Shasta Reservoir area infrastructure. For raises in joint use elevation below 20 feet, no large break-points exist, and buildings, roads, and bridges account for the majority of the costs.

CHAPTER VI
COMBINED SHASTA DAM AND RESERVOIR AREA INFRASTUCTURE BREAK-POINTS

The cost curves for the dam and the reservoir area infrastructure were combined to obtain one cost curve for enlarging Shasta Dam and Reservoir, shown in **Figure 19**. This plot does not represent the total project cost for enlarging Shasta Dam and Reservoir (for example, real estate costs, mitigation costs, design costs, and construction management costs are not included), but is intended to reflect the locations of significant break-points in cost for the project. Accordingly, it should not be directly correlated with the estimates of total first costs in **Figure 2**. Again, the primary purpose of **Figure 19** is to illustrate the combined dam and reservoir area infrastructure break-points.

In order to combine the cost curves with a consistent elevation reference, the costs for Shasta Dam and Appurtenances were adjusted from dam crest elevations to joint use elevations. The dam raise options in the 1998 Reclamation Technical Memorandum include 8.5 feet of freeboard between the joint use elevation and the crest of the dam (freeboard on the existing dam is 10.5 feet), so the dam crest elevations were adjusted to joint use elevations by subtracting 8.5 feet.

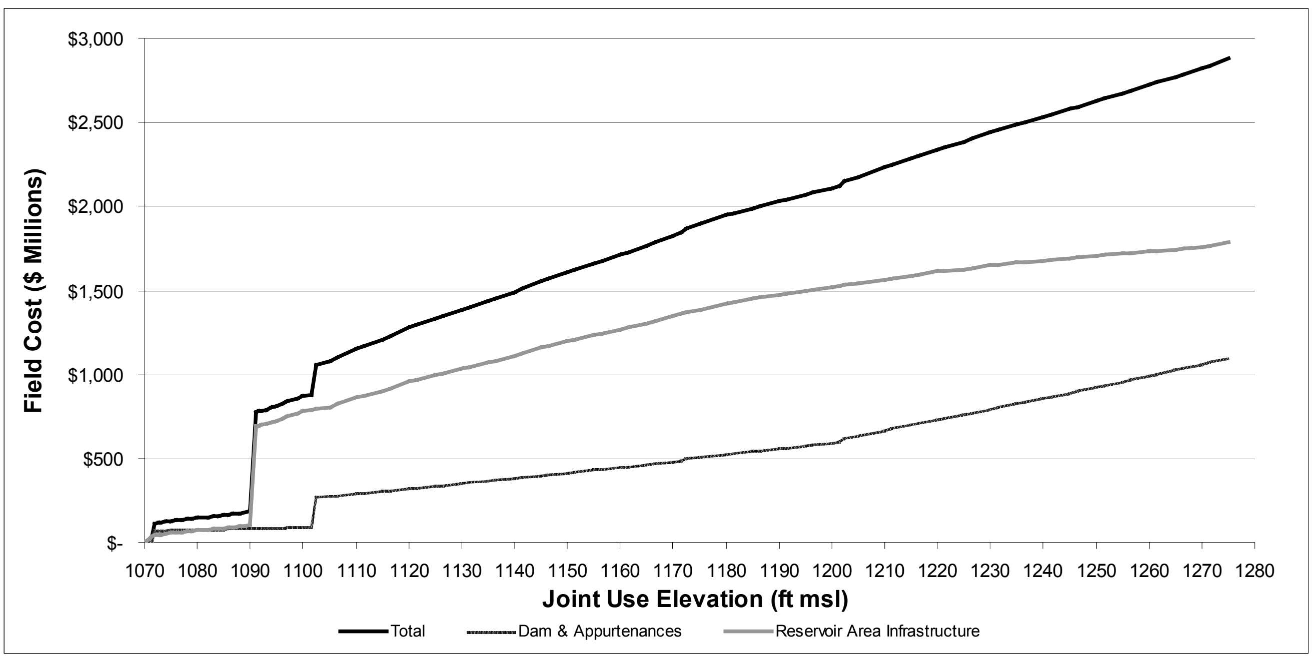


Figure 19 – Costs Associated with Raising Shasta Dam and Relocating Shasta Reservoir Area Infrastructure

As shown in **Figure 19**, the first major break-point in cost on the total curve is located above a 20-foot raise in the top of joint use (gross pool) elevation, where the Pit River Bridge would need to be relocated, along with portions of I-5 and UPRR. The 1999 Reclamation Appraisal Report shows a 2-foot reduction in freeboard for the dam raise options, so a raise in top of joint use elevation of 20 feet would correspond to a dam raise of 18 feet. The second major break point above a 32–foot raise in the top of joint use elevation (30-foot dam raise) is at the point where the method of raising the main dam structure changes, the middle tier of outlet gates is replaced, cofferdams are required, and the penstocks within the dam are replaced. The third break-point above a 102-foot raise in joint use elevation (100-foot dam raise) is at the point where isolation valves for the penstocks are required. The fourth break-point above a 132-foot raise in joint use elevation (130-foot dam raise) is at the point where the upper tier of river outlet gates is replaced. The third and fourth break-points are much smaller than the first and second break-points.

For raises in top of joint use elevation less than 11 feet (9-foot dam raise), the costs for modifications to the dam are higher than for infrastructure relocations. Above a top of joint use elevation raise of 11 feet, the costs for reservoir infrastructure are higher than for the dam. Above a top of joint use elevation raise of 20 feet, the Pit River Bridge relocation incurs a major cost and is the largest break-point in the analysis. The major break-point for the dam is just above a 30-foot dam raise when mass concrete would need to be added to the face of the dam, not just the dam crest. All of the other features discussed in this report that contribute to the costs of enlarging Shasta Dam and Reservoir do not have major break points when compared to the total costs.

CHAPTER VII
FINDINGS

The major findings of this report are:

GENERAL

- There are two fundamental cost components associated with raising Shasta Dam and enlarging Shasta Reservoir: (1) modifications to the main dam and appurtenances and (2) modifications to reservoir area infrastructure and facilities.

- There appears to be distinct discontinuities or "break-points" in the costs of construction modifications required for each fundamental component with increasing dam heights and reservoir sizes. The largest discontinuities occur at dam raises of about 18 feet and 30 feet.

DAM AND APPURTENANCES

- The major cost component for increases in the height of Shasta Dam are associated with the mass concrete used in raising the main dam and wing dams with the major costs beginning with raises in excess of 30 feet. Raises up to 30 feet will only require modification of the dam crest; major modification of the existing main dam monolith would not be required. Further study is needed to verify this estimate.

- For any raise of Shasta Dam the spillway and temperature control device would need to be modified, structures would need to be removed from the dam crest, and the lower tier of river outlet valves would be replaced.

- Major modifications and costs related to the main dam structure, wing dams, river outlets, and penstocks occur with dam raises in excess of about 30 to 50 feet.

- Major modifications and costs related to the addition of isolation valves for the penstocks occur with dam raises in excess of about 100 feet.

- Major modifications and costs related to the replacement of the upper tier of river outlet gates occur with dam raises in excess of about 130 feet.

- Many of the other dam and appurtenance features contribute to the overall costs of enlarging Shasta Dam and Reservoir, but do not have major break points when compared to the total costs. They include, but are not limited to dam crest structure removal, modifications to the TCD, and cofferdams.

RESERVOIR AREA INFRASTRUCTURE

- For any raises in the top of joint use (gross pool) elevation of Shasta Reservoir, a number of bridges would either need to be relocated or, if possible, low structural members would need to be protected from inundation. A number of buildings would also need to be relocated or abandoned with any raise in top of joint use elevation.

- The major break-point in costs for increasing in the size of Shasta Reservoir occurs with a top of joint use (gross pool) raise above 20 feet, which corresponds to a dam raise of about 18 feet, due primarily to the need for major relocations of I-5 and the UPRR at the Pit River Bridge.

- A maximum dam raise of 18 feet was selected because larger raises would result in seasonal periodic water surface elevations at the Pit River Bridge to reach a point of significant adverse impact to the structures and severe restriction of lake watercraft passage. Above a dam raise of 18 feet, the Pit River Bridge relocation incurs a major cost and is the largest break-point in the analysis.

- It is estimated that potential impacts to the Pit River Bridge resulting from dam raises up to about 18 feet (top of joint use increase of about 20 feet) can be mitigated with structural protective measures combined with aggressive additional maintenance at the structures and a program of lake watercraft management. Additional study is necessary to determine the best method of protection.

- Many of the other reservoir area infrastructure features contribute to the overall costs of enlarging Shasta Dam and Reservoir, but do not have major break points when compared to the total costs. They include, but are not limited to, remediation of impacts to buildings and minor roads, clearing and seepage mitigation, and construction of reservoir dikes.

COMPARISON

- For a dam raise of 18 feet, the costs for the dam and appurtenances, and reservoir area infrastructure amount to approximately 45 and 55 percent of the combined cost, respectively.

- For a dam raise just above the major break-point of 18 feet, where relocation of the Pit River Bridge is required, nearly 50 percent of the total cost is related to that relocation.

- For dam raises less than 9 feet, the costs for modifications to the dam and appurtenances are higher than for reservoir area infrastructure relocations. Above 9 feet the costs for reservoir area infrastructure relocations are higher than for modification to the dam and appurtenances.

CHAPTER VIII
BIBLIOGRAPHY

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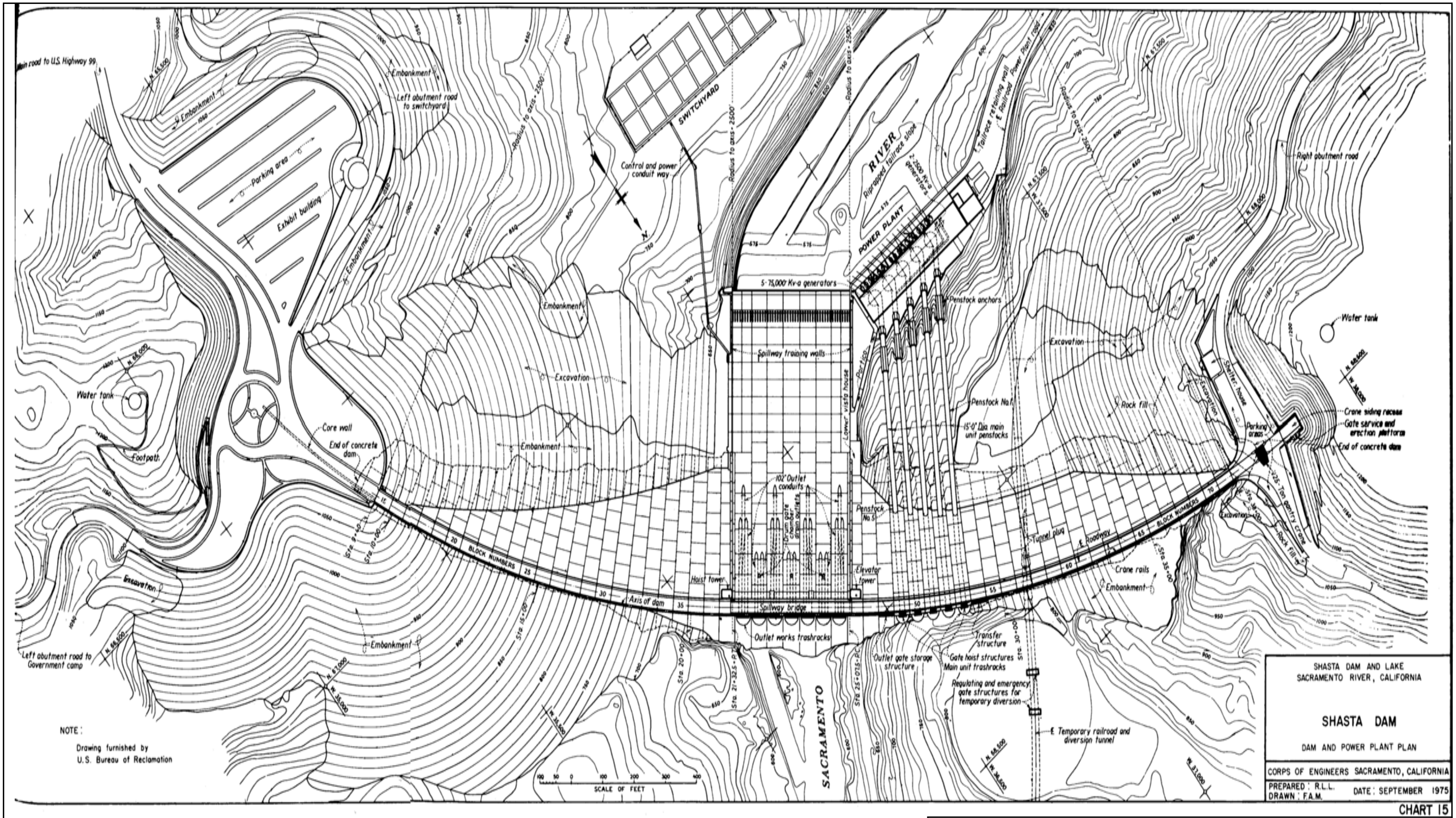
PLATES



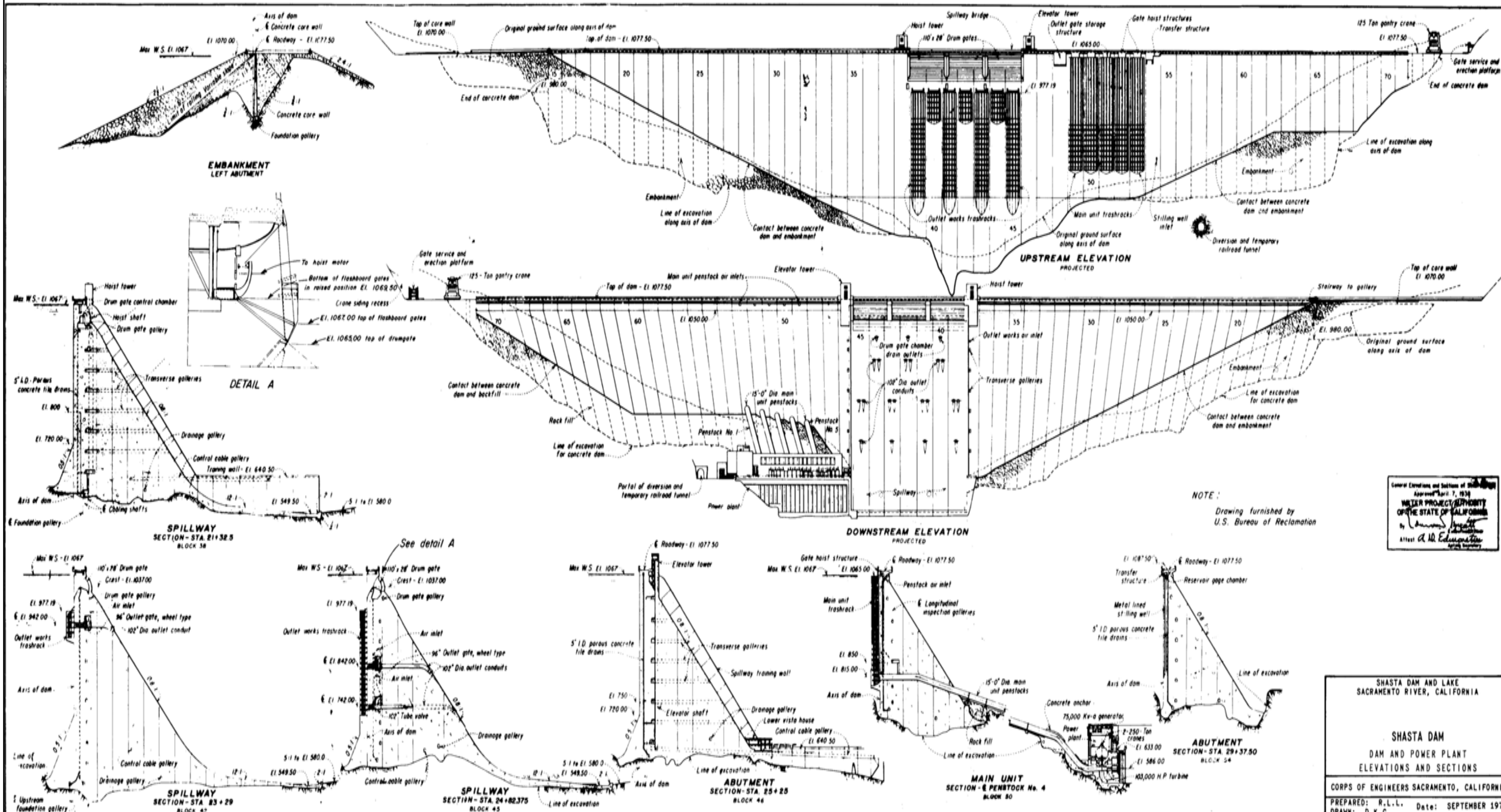
Source: U.S. Army Corps of Engineers, Shasta Dam and Lake, Sacramento River, California, Report on Reservoir Regulation for Flood Control, Rev. January 1977.

Shasta Lake Water Resources Investigation, California

SHASTA DAM AND POWERPLANT PLAN

U.S. Bureau of Reclamation, Mid-Pacific Region
June 2003

PLATE 1



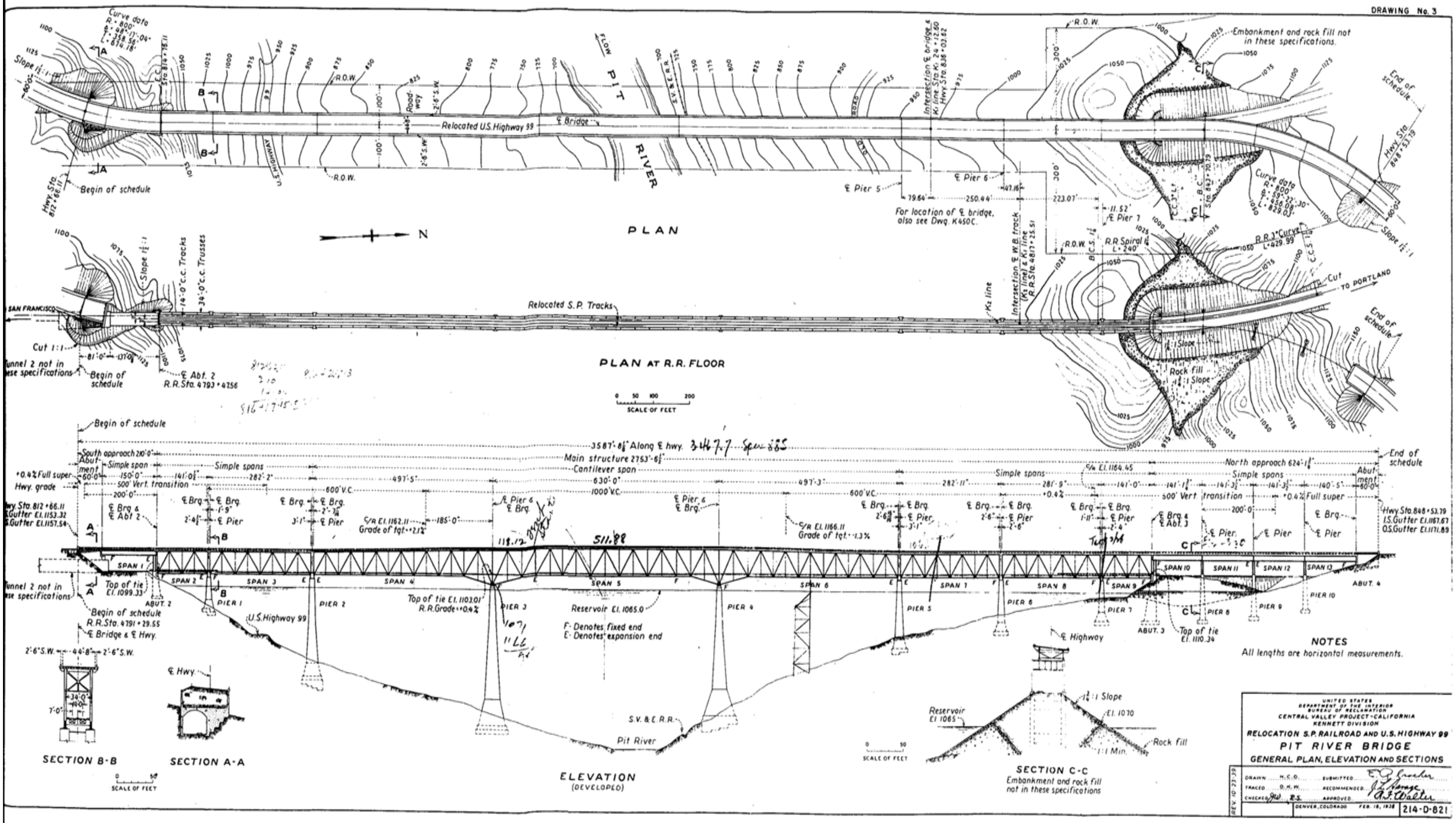
Source: *U.S. Army Corps of Engineers, Shasta Dam and Lake, Sacramento River, California, Report on Reservoir Regulation for Flood Control, Rev. January 1977.*

Shasta Lake Water Resources Investigation, California

SHASTA DAM AND POWERPLANT ELEVATIONS AND SECTIONS

U.S. Bureau of Reclamation, Mid-Pacific Region
June 2003

PLATE 2



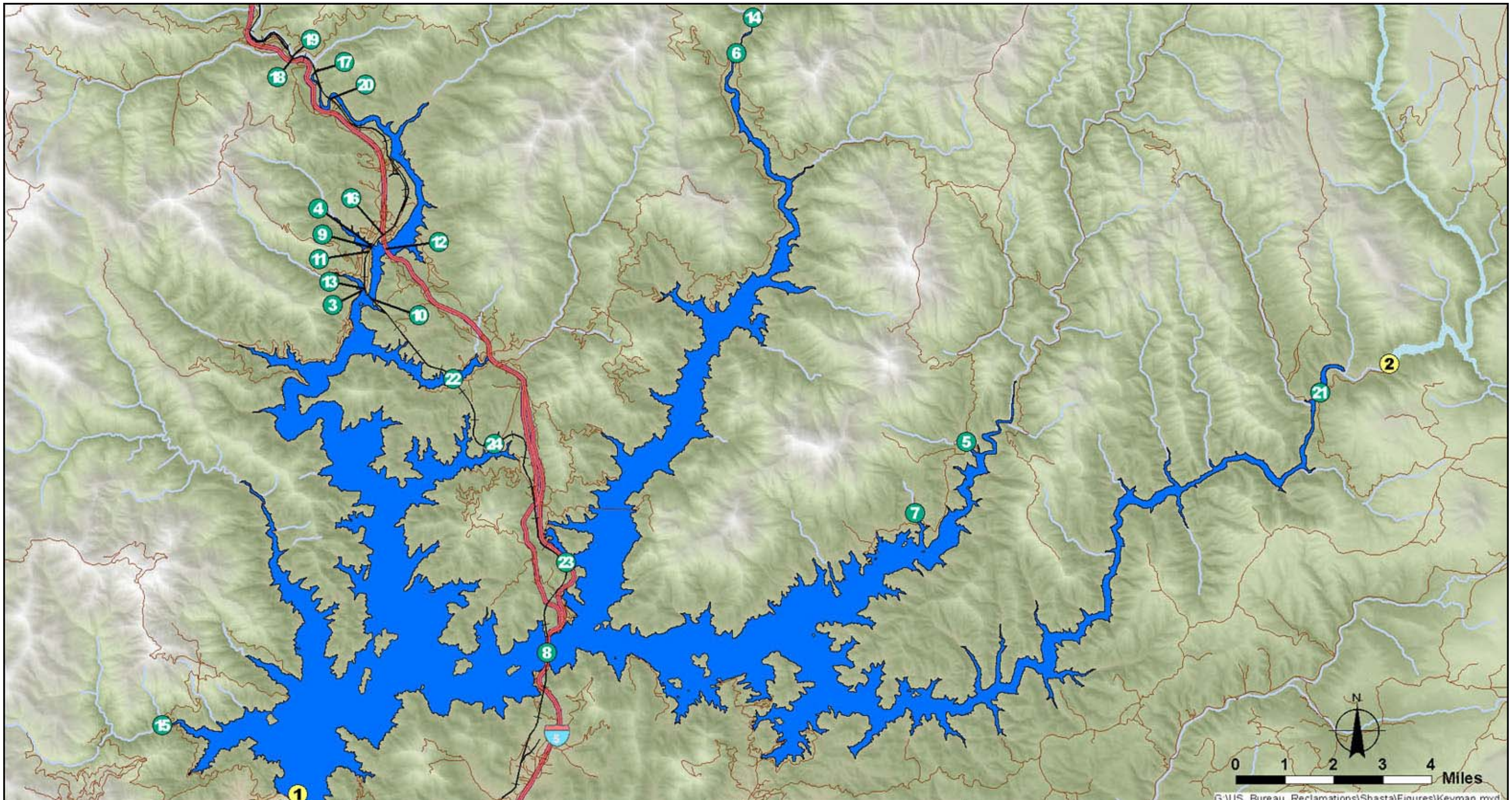
Source: *U.S. Bureau of Reclamation, Abutments and Piers, Pit River Bridge, Relocation of Southern Pacific Railroad and U.S. Highway 99, 1939.*

Shasta Lake Water Resources Investigation, California

PIT RIVER BRIDGE

U.S. Bureau of Reclamation, Mid-Pacific Region
June 2003

PLATE 3



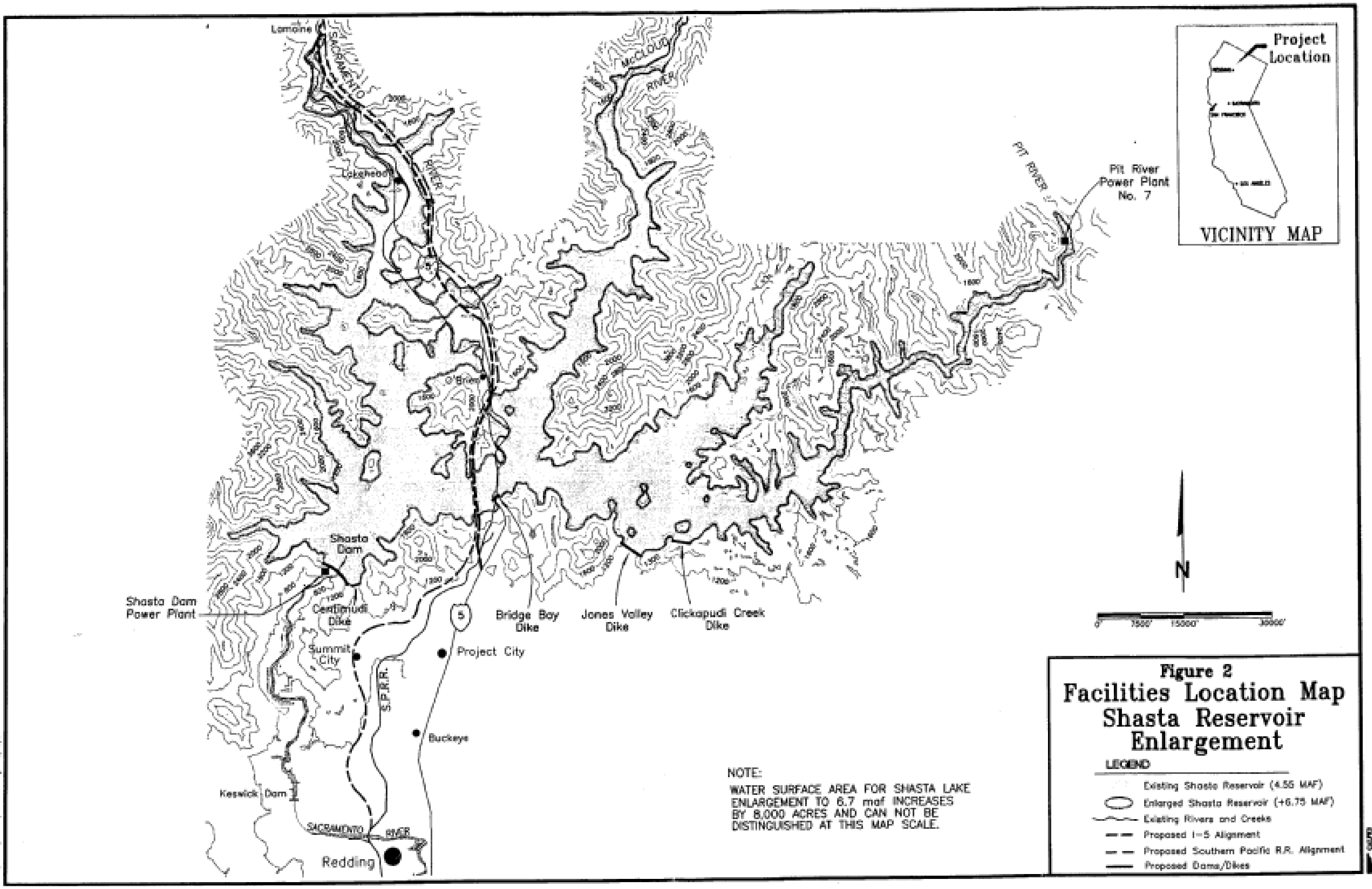
ID	Name	Agency	ID	Name	Agency
1	Shasta Dam	Bureau of Reclamation	13	Lakeshore Drive Overcrossing by Charlie Creek	Union Pacific
2	Pit 7 Dam	PG&E	14	Wittawaket Creek Bridge	private
3	Charlie Creek Bridge	Shasta Co.	15	Squaw Creek Bridge	Shasta Co.
4	Doney Creek Bridge	Shasta Co.	16	Interstate 5 Overpass	Union Pacific
5	Didallas Creek Bridge	USFS	17	Sacramento River 4th Crossing	Union Pacific
6	McCloud River Bridge	USFS	18	Dog Creek Bridge	Union Pacific
7	Second Creek Bridge	USFS	19	Fender Ferry Bridge (Sacramento River)	USFS
8	Pit River Bridge	Caltrans/Union Pacific	20	Sacramento River 3rd Crossing	Union Pacific
9	Doney Creek Bridge	Union Pacific	21	Fender Ferry Bridge (Pit River)	USFS
10	Sacramento River 2nd Crossing	Union Pacific	22	Salt Creek Bridge	Union Pacific
11	Lakeshore Drive Overcrossing by Doney Creek	Union Pacific	23	Tunnel Gulch Viaduct	Caltrans
12	Antlers Bridge	Caltrans	24	O'Brien Creek Bridge	Union Pacific

Shasta Lake Water Resources Investigation, California

DAM AND BRIDGE LOCATIONS

U.S. Bureau of Reclamation, Mid-Pacific Region
June 2003

PLATE 4



Source: CALFED Storage and Conveyance Refinement Team, Facility Descriptions and Updated Cost Estimates for Shasta Lake Enlargement, October 1997.

Shasta Lake Water Resources Investigation, California

RESERVOIR DIKE LOCATIONS

U.S. Bureau of Reclamation, Mid-Pacific Region
June 2003

PLATE 5

Shasta Lake Water Resources Investigation,

California

Break-Point Analysis Office Report

APPENDIX

BREAK-POINT ANALYSIS SITE VISIT MEMORANDUM

June 2003

Note:

The elevations given in this site visit memorandum are in the vertical datum of NGVD 1929, which is different from the vertical datum used in the elevation references in the break-point analysis office report (NAVD 1988). For instance, at Shasta Dam, NAVD 1988 elevations are 2.66 feet higher than NGVD 1929 elevations.

28 May 2003

MEMORANDUM FOR RECORD

SUBJECT: Shasta Lake Water Resources Investigation – Break-Point Analysis Site Visit

1. A site visit of the Shasta Dam and Reservoir Area was conducted during the period 20 through 22 May 2003. The primary purpose of the site visit was to better understand the relationship between raising Shasta Dam and Reservoir and the needs for major facilities and infrastructure modifications.

2. Enclosure 1 is an itinerary for the site visit. Enclosure 2 is a list of individuals who participated for either all or portions of the site visit and associated discussions.

3. On Tuesday (20 May), following a brief introduction presentation by MWH at the Bridge Bay Resort and Marina, most of the participants visited major infrastructure within the reservoir area that could be subject to modification with increasing water surface elevations. This included several sections of the Union Pacific Railroad line (UPRR), Pit River Bridge, Antlers Bridge and Campground, and road and railroad bridges along Doney Creek, Charlie Creek, and the Sacramento River. On Wednesday (21 May) morning, the group viewed Shasta Dam. Due to a heightened national security alert status, only the top of the Dam was accessed. Following discussions on Wednesday afternoon regarding the observations made in the reservoir area on 20 May and at Shasta Dam, the group toured the Pit 7 Dam on the Pit River. A brief wrap-up meeting was held on Thursday (22 May) morning on the observations made during the previous 2 days.

4. Raising Shasta Dam and the gross pool levels of Shasta Reservoir would result in the need to modify increasing numbers and amounts of various facilities and appurtenances at Shasta Dam and infrastructure in and around Shasta Reservoir. Many of the dam appurtenances and reservoir area infrastructure impacts would be relatively linear – some impacts at lower elevations and increasing generally proportionally as the dam height and gross pool levels increase. However, for some of the dam features and appurtenances and reservoir area infrastructure there would be requirements for major modifications at specific dam heights or elevations in the raise of the gross pool. Following are the general observations made and agreements reached during the field inspection and related meetings and discussions regarding potential break-points associated with raising Shasta Dam and the gross pool elevation of Shasta Reservoir. All elevations are given in the vertical datum NGVD 1929.

5. **Shasta Dam** – It was discussed and agreed that potential project modifications contributing to the overall cost to raise Shasta Dam but thought to generally be required for any raise and/or required in varying degrees for increasing raises include: (1) modifications to the existing temperature control device (TCD), (2) modifications to the existing spillway, and (3) removal of existing structures at Shasta Dam to allow any modifications. The TCD would need to be modified for essentially any raise in water surface elevation of over about 2 to 3 feet. The TCD modifications would range from

simply raising the structure and related control system for lower raises to enlargement of the facility for higher raises - in excess of about 100 foot dam raise. The existing spillway and spillway gates would be modified for any raise. The modification would include reconstructing the spillway, and spillway crest, and replacing the 3 sets of existing drum gates either with similar drum gates for lower raises or tainter gates at higher dam raises. Tainter gates for the higher raises would be approximately ½ the length of the existing gates. Removal and replacement of the existing roadway, parapet wall, crane rails, and related features would be needed for any dam raise.

It was also discussed and agreed that features that were sensitive at specific levels of dam raise include the (1) main dam enlargement, (2) wing dams and cofferdams, (3) river outlets, (4) penstocks, and (5) powerhouse. Following is a brief discussion of the major facilities and their estimated break-points for raising Shasta Dam.

a. Main Dam Enlargement (Figure 1) – In Reclamation's 1999 Appraisal Report (Appraisal Assessment of the Potential for Enlarging Shasta Dam and Reservoir), it was estimated that for a 6.5 foot raise the dam crest would be raised by additional concrete block lifts. For raises of 100 and 200 feet, the entire dam mass would be increased (crest and face). It was agreed during the site assessment, however, that for potential dam raises of a magnitude approximately equal to the width of the existing dam crest (30 feet), raising the existing dam crest in blocks could be considered feasible. For dam raises generally greater than about 50 feet, overlaying the existing dam with concrete mass and progressively enlarging the dam base should be considered.

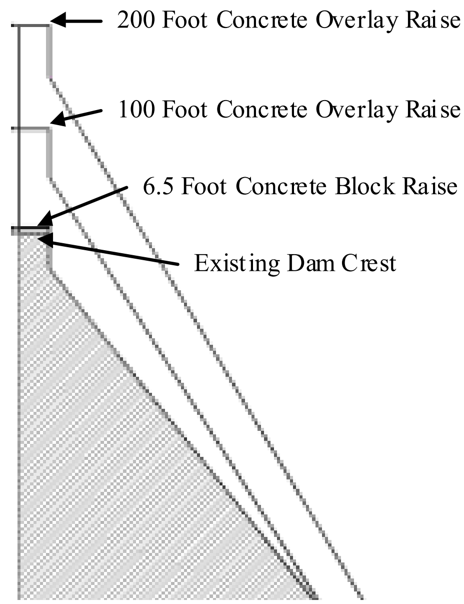


Figure 1 – Cross section of Shasta Dam for Various Dam Raises.

b. Wing Dams – It was agreed that for dam raises generally requiring additional block lifts (up to approximately 30 feet), that the existing reinforced earth wing dams could be enlarged using the similar reinforced earth designs. For lower raises, the enlarged reinforced earth wing dams would be constructed of earth filled embankments with an impervious core and keyed to impermeable material. For dam raises greater than about 30 to 50 feet, the wing dams would need to be concrete structures. For dam raises greater than 30 to 50 feet, cofferdams would need to be constructed at each dam abutment to facilitate construction of the wing dams.

Photo 1 – Shasta Dam Spillway and Flood Control Outlets.

c. River Outlets (Photo 1) – Currently, Shasta Dam has 18 outlets in three tiers. There are four 102-

inch lower tier outlets (invert elevation 737.75 feet), eight 96-inch mid-level tier outlets (invert elevation 837.85 feet), and six 96-inch upper level tier outlets (invert elevation 937.75 feet). It was agreed that all the valves for the lower tier outlets would be replaced for any dam raise. It was also agreed that for dam raises above about 30 to 50 feet, the 8 middle tier valves would be replaced. The six upper tier outlets would be adequate for raises up to 100 feet.

d. **Penstocks** (Photo 2) – There are 5 – 15 foot diameter steel penstocks running through the dam mass and to the downstream powerhouse. It was agreed that the exposed sections of the penstocks are adequate for dam raises to the maximum elevations considered. However, for dam raises above approximately 30 to 50 feet, the sections of the penstocks within the dam mass would need to be replaced. This is because of the potential for collapse due to excessive exterior pressures should the penstocks become de-watered.

Photo 2 – Power Penstocks and Powerhouse at Shasta Dam.

e. **Powerhouse** (Photos 2 and 3) – There are 5 main Francis-type turbines located in the powerhouse near the downstream toe of Shasta Dam. It was agreed that all the turbines would need to be replaced for dam raises above 100 feet and that the replacement would likely require construction of a new power plant. For essentially all dam raises lower than 100 feet, there would need to be some modification to the existing generating system but additional studies are required to identify the specific modifications needed. The modifications would depend on the extent of dam raise – head on the turbines and ancillary equipment.

Photo 3 – One of 5 Main Generator in Shasta Powerhouse.

6. **Shasta Reservoir Area** – It was discussed and agreed that potential project features contributing to the overall cost of raising the height and increasing the gross pool elevation of Shasta Lake, but thought to generally be required for any raise and/or required in varying degrees for increasing raises include: (1) buildings, (2) roads, (3) reservoir dikes, (4) environmental and related resources mitigation, and (5) recreation facilities. It was also discussed and agreed that features that were gross pool raise sensitive included (1) relocating Interstate 5 (I-5) and associated bridges, (2) relocating Union Pacific Railroad (UPRR) and associated bridges, and (3) modifying the Pit 7 Dam. Following is a brief discussion of the major reservoir area infrastructure and their estimated break-points.

a. **Pit River Bridge** (Photos 4 and 5) – The Pit River Bridge includes two levels. The top level accommodates north-south vehicular traffic of I-5. The lower level accommodates UPRR traffic. The bridge was designed and is owned by the Bureau of Reclamation, however, Caltrans and UPRR are responsible for inspection and maintenance. Given the age of the mostly steel bridge (approximately 60 years), the structure is in good condition. The tops of the concrete sections of the two center piers are near gross pool elevation with the top of Pier 3 at gross pool (elevation 1067). Any raise of the gross pool elevation of Shasta Lake would cause some periodic inundation to the lower portion of the bridge superstructure at Pier 3. With higher raises, more of the superstructure would be impacted as additional piers become overtopped beginning with Pier 4 (elevation 1069.5 feet). The lowest top of concrete elevation of the other higher piers (see Photo 5) is Pier 1 at 1088.58 feet.

Pier 4 – Top of Concrete @ 2.5 Feet Above Current Gross Pool.	Pier 3 – Top of Concrete @ Current Gross Pool.

Photo 4 – Pit River Bridge Looking East – 18 December 2002.

Photo 5 – Pit River Bridge Looking South – 20 May 2003.

It was concluded that some periodic and infrequent inundation of a portion of the bridge superstructure would likely be feasible provided there were capabilities to adequately protect and maintain the structural bridge components. It was expressed that using protective coatings of the structural members even with aggressive maintenance would probably not be feasible due to the potential for induced damage. It was generally agreed that to insure the integrity of structural members that would be at or below a new gross pool elevation, they should not be subject to inundation. It is believed that even with infrequent inundation, protective measures would likely need to be some kind of enclosure of the structural members. However, this type of structural protection becomes infeasible for gross pool raises above the lower cords of the bridge (elevation 1091.5 at southern end of bridge). The UPRR stated in previous correspondence that a minimum clearance of 4 feet below the bridge low cord could be acceptable. This would translate into a maximum gross pool elevation of about 1087.5. A raise in gross pool to this elevation, about 20.5 feet, would be about 0.5 feet below the concrete lip of Abutment 2 at the south end of the bridge. With enclosure of the low bearings and trusses at Piers 3 and 4, a gross pool raise of 20.5 feet would not result in inundation (other than from wind and wave action at gross pool) of any structural members of the bridge.

The roadway and rail line of the Pit River Bridge have a positive slope to the north. The top of the concrete section of Piers 6 and 7, which are the two closest to the north abutment, are 1096.75 and 1098.47, respectively. Accordingly, the elevation difference between the maximum gross pool elevation of 1087.5 feet msl and the top of concrete at Piers 6 and 7 amounts to 9.25 and 10.97 feet, respectively. A raise in gross pool by about 20.5 feet, to maintain the UPRR minimum clearance (4 feet) at the south abutment, would leave a minimum clearance between the water surface at gross pool and bottom of bridge the low cord between Piers 6 and 7 of approximately 13.3 feet. This would be sufficient for small watercraft but would limit some larger houseboats. Providing 20 feet of clearance for houseboats would reduce the allowable gross pool raise to about 13.8 feet. The U.S. Coast Guard has guidelines for navigational clearances, so they should be contacted and consulted with to ensure that the proper clearances are provided, since they may be different from what is being assumed is acceptable.

b. Antlers Bridge (Photo 6) – The Antlers Bridge, which supports a section of I-5, is located about 9 miles north of the Pit River Bridge. It is a steel structure and has a history of fatigue and safety issues. It was designed by Caltrans and it is considered a "fracture critical" bridge, which means that it is subject to partial or complete collapse if one of the "fracture critical" structural members should fail. Caltrans is in the process of preparing preliminary designs of a replacement structure with an alignment immediately east of the existing bridge. The replacement is in their long-range plans.

Photo 6 – Antlers Bridge Looking South – 20 May 2003.

Any raise of the gross pool to Shasta Lake would begin to inundate portions of the Antlers superstructure and, given the condition of the bridge, would require full replacement. However, as the bridge is expected to be replaced within the planning and design periods of a modification to Shasta Dam and Reservoir, that replacement will be included in the without-project condition. Current preliminary designs by Caltrans are for the replacement bridge to be raised 6 to 8 feet above the existing bridge to allow for a potential dam raise of about 6.5 feet, and better match existing topography. Any plans for a raise higher than 6 to 8 feet in gross pool elevation of Shasta Lake need to be communicated with Caltrans engineers so that the bridge and roadway design provides adequate clearances.

c. Doney and Charlie Creek Bridges (Photos 7 and 8) – These two bridges carry vehicular traffic. The current gross pool of Shasta Lake inundates the bridge piers and much of the superstructure for both the Doney and Charlie Creek bridges. It was agreed that with any raise of gross pool both bridges would be inundated and need to be replaced or abandoned.

Photo 7 – Doney Creek Bridge – 20 May 2003.

Photo 8 - Charlie Creek Bridge – April 2002.

d. Doney and Sacramento River 2nd Crossing UPRR Bridges (Photos 9 and 10) – The current gross pool level of Shasta Lake is 3 inches below the top of concrete of the lowest pier (Pier 1) of the UPRR Doney Creek Bridge, and 10 inches above the top of concrete on the lowest pier (Pier 5) of the UPRR Sacramento River 2nd Crossing Bridge. It was agreed that with any increase in gross pool that both railroad bridges would need to be replaced.

Photo 9 – Doney Creek UPRR Bridge – 20 May 2003.

Photo 10 – UPRR Sacramento River 2nd Crossing – 20 May 2003.

e. I-5 @ Salt Creek – Salt Creek flows west under I-5 through a large diameter box culvert. The roadway is constructed on about 50 to 70 feet of fill above gross pool elevation at this location. Large increases in gross pool elevations would inundate roadway fill on both the west and east side of the interstate. Lower raises of gross pool, up to about 15 feet, could likely be accomplished without modifications to the existing embankment. Higher raises would likely require some amount of remediation. Geotechnical analysis of any raise in gross pool would be required.

f. UPRR @ Bridge Bay (Photo 11) – There is approximately a 700-foot length of exposed UPRR track between two tunnels at the southern edge of the Bridge Bay Marina. The top of the ballast of the railroad is about 13 feet above the existing gross pool elevation at the southern end of the exposed track. There is a culvert under the track at this location to help drain a small area to the east of the track at this location. It was agreed that low level raises in gross pool over about 8 feet would require embankments on both the east and west side of the railroad at this location to protect the railroad. Sufficient area is available to construct embankments for gross pool raises up to 20 feet. As the Pit River Bridge and UPRR would be relocated for gross pool raises above 20 feet, this railroad segment would be assessed as part of the bridge replacement for higher raises.

Photo 11 – UPRR Track at Bridge Bay.

g. Lakeshore Drive – Lakeshore Drive connects residences, resorts, and recreation facilities along the western rim of Shasta Lake near the community of Lakeshore. Various reaches of the existing road alignment would be inundated with lower level gross pool raises. These reaches of roadway would either need to be relocated outside of a raised the gross pool or abandoned. As previously discussed, the costs associated with roadway relocations would be a relatively linear function of increases to gross pool elevation.

h. Pit 7 Dam (Photos 12 and 13) – Constructed in the mid 1960's, the Pit 7 Dam is a 200 foot high dam on the Pit River at the headwater of Shasta Lake. It is owned and operated for hydropower generation by the Pacific Gas and Electric Company (PG&E). The power plant for the dam includes two 56 MW turbines with maximum flows through the power plant of 7700 cfs. The power plant is on 4 levels with the top level exposed. The lower levels included the control room, turbines, and associated equipment.

The stilling basin lip elevation is at elevation 1075.5 feet (8.5 feet above existing gross pool of Shasta Lake). The elevation of the wing walls to the existing stilling basin is 1094.0 feet and the elevation of the powerplant yard is 1104.2 feet. The maximum raise in gross pool elevation before encroachment into the powerplant yard, excluding consideration of a PMF surcharge, would be about 37 feet.

Photo 12 – Pit 7 Dam Spillway and Stilling Basin – 21 May 2003

Potential impacts of low level raises of the Shasta Lake gross pool would primarily include (1) reduced hydropower generation during periods of elevated water surface elevations, potential reductions in existing spillway capacities, and (3) added stresses to the side walls of the power plant.


Photo 13 – Pit 7 Dam – December 2002.

It was agreed that raising the gross pool elevation of Shasta Lake by up to about

20 feet could be accomplished without major modifications to the dam or appurtenances. Higher raises would likely result in the need for major relocations and modifications to the dam and hydroelectric facilities. Further studies to identify and assess potential impacts and remedial measures for low-level raises were recommended by the site visit team.

7. It was understood that the information obtained during the site visit would be used to prepare a Break-Point Office Report for inclusion into the feasibility studies for the subject investigation.

Donna Garcia
Project Manager
Mid-Pacific Region, U.S. Bureau of Reclamation

SHASTA LAKE WATER RESOURCES INVESTIGATION
20-22 MAY 2003 BREAK-POINT SITE VISIT
ITINERARY

DAY 1: Tuesday, May 20, 2003

7:30 a.m.	Depart assembly location
10:30 a.m.	Arrive at Bridge Bay Resort and Marina Meeting Facility Start Kick-Off Meeting
11:45 a.m.	Lunch at Bridge Bay Resort and Marina, Tail O' The Whale Restaurant
12:45 p.m.	Arrive at U.P. Railroad between Tunnels 1 & 2 (S. end of Bridge Bay)
1:30 p.m.	Arrive at Pit River Bridge
3:00 p.m.	Arrive at Antlers Bridge
4:15 p.m.	Arrive at Antlers Campground
4:45 p.m.	Arrive at Doney Creek Bridges- U.P. Railroad and Lakeshore Drive
5:30 p.m.	Arrive at U.P. Railroad Sacramento River 2nd Crossing Bridge
6:00 p.m.	Depart for Hotel in Redding
6:30 p.m.	Arrive at Hotel in Redding

DAY 2: Wednesday, May 21, 2003

7:30 a.m.	Depart Hotel for Shasta Dam
8:00 a.m.	Tour of Shasta Dam- powerhouse, penstocks, outlet works, spillway, temperature control device
11:30 a.m.	Lunch
12:30 p.m.	Working Meeting at Bridge Bay Resort and Marina Meeting Facility
3:00 p.m.	Depart for Pit 7 Dam
4:00 p.m.	Tour of Pit 7 Dam
5:00 p.m.	Depart for Hotel in Redding

DAY 3: Thursday, May 22, 2003

7:45 a.m.	Depart Hotel for Bridge Bay Resort and Marina
8:00 a.m.	Arrive at Bridge Bay Resort and Marina Meeting Facility Start Wrap-Up Meeting
11:00 a.m.	Depart for Sacramento

SHASTA LAKE WATER RESOURCES INVESTIGATION
20-22 MAY 2003 BREAK-POINT SITE VISIT
LIST OF PARTICIPANTS

U.S. Bureau of Reclamation

Donna Garcia	- Project Manager, Sacramento Regional Office
Steve Lloyd	- Dam Design Engineer, Sacramento Regional Office
Jesus Romero	- Bridge Engineer, Denver Technical Service Center
Tom Hepler	- Dam Design Engineer, Denver Technical Service Center
George Gardner	- Engineer & Tech Services, Northern CA Area Office
Larry Ball	- Operations, Northern CA Area Office
Jim Destaso	- Environmental Resources, Northern CA Area Office

Caltrans

Erol Kaslan	- Bridge Engineer
Steve Wiman	- Bridge Engineer

California Department of Water Resources

Sam Linn	- Engineer
Brian Heiland	- Engineer
John Yarbrough	- Engineer

MWH

Merritt Rice	- Program Manager
Mary Paasch	- Project Manager
Ryan Murdock	- Project Engineer
Jeff Weaver	- Project Engineer
Jim Witnik	- Structural Engineer
Mike Manwaring	- Geotechnical Engineer/Geologist

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